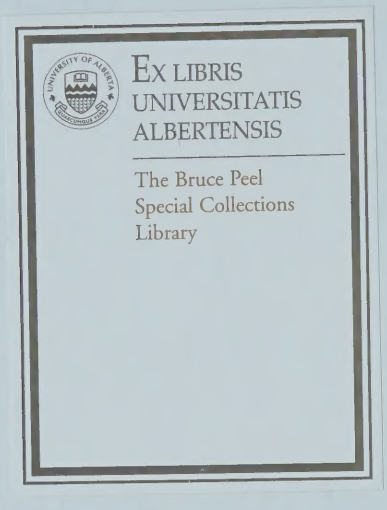
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Selection of Forages for Vegetated Buffers Within Wetland-Cropland Ecotones Based on Salt and Flooding Tolerance

by

Barbara Lynn Logan

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science

in

Water and Land Resources

Department of Renewable Resources

Edmonton, Alberta

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University of Alberta

Faculty of Graduate Studies and Research

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled **Selection of Forages for Vegetated Buffers Within Wetland-Cropland Ecotones Based on Salt and Flooding Tolerance** submitted by **Barbara Lynn Logan** in partial fulfillment of the requirements for the degree of **Master of Science** in **Water and Land Resources**.

Abstract

Wetland conservation is a landscape-scale endeavor, encompassing both the wetland basin and the transition zone between wetland margins and agricultural uplands (wetland-cropland ecotone). The ecotone is a complex area where gradients in water regime and salinity exist. Implementing vegetated buffer strips consisting of salt and flood tolerant perennial forages within the ecotone offers a strategy for protecting the wetland while still allowing agriculture to continue over the broader landscape. To screen species for possible use within the ecotone, germination rates, survival, above and below ground biomass production of forages were studied under levels of $MgSO_4$ and Na_2SO_4 up to 12 dS/m and flooding durations up to 4 weeks. The effects of soil texture and extreme salinity were also tested. Salinity had a far greater impact on plant success than flooding; soil texture did not significantly affect salt or flood tolerance. Alkali grass and tall fescue were highly salt tolerant.

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1. General Introduction

1.1 Sustainable Agriculture in the Prairie Pothole Region

As the human population continues to grow while the amount of arable land declines (Flowers et al., 1986), the need for safe, productive and sustainable agricultural practices becomes increasingly apparent. In the past, agricultural practices rarely took into account the principles of conservation and environmental protection, largely because landowners and policy makers were unaware of the consequences of not doing so (Bregha et al., 1998). Often, practices thought to be sound turned out to have deleterious, long-term impacts not considered at the time of implementation (e.g. the use of summerfallow to conserve soil moisture was later found to exacerbate salinity and soil erosion). Over the last decade, increasing emphasis and effort have been placed on practicing sustainable agriculture (McRae et al., 2000).

By definition, sustainable agriculture meets current needs while leaving equal or better opportunities for the future (Ikerd, 1999). By applying ecological concepts to farming, the goal of sustainable agriculture is to preserve the integrity, stability and beauty of the biotic community while maintaining farm profitability and rural vitality. In order to meet objectives of environmental protection, which includes the protection of surface and ground-water quality, air quality, soil quality, wetlands and wildlife habitat, consideration must first be given to profitability for the landowner (or at least, minimization of cost) in order for sustainable practices to be adopted. By including economics, the environment and social aspects in a more holistic approach to practicing agriculture, we diminish the risk of system collapse over the long term (Savory, 1988).

The prairie pothole region of western Canada and the north central United States is an inherently fertile area, the predominant land use of which has become agricultural production (Martin and Hartman, 1987). Over the course of time, this production has had a detrimental effect on the numerous small wetlands within the prairie region (Environment Canada, 1986; Mensing et al., 1998), the impacts of which include drainage and contamination with agricultural chemicals and sediment (Martin and Hartman, 1987; Gregorich et al., 2000).

Prairie pothole wetlands are the water-holding depressions of glacial origin (Sloan, 1972; Richardson et al., 1994), that are spread throughout the prairie region (see Figure 1.1). These potholes, sloughs and wetlands as they are known, may range in size from a few square meters to large lakes and from deep, permanent water bodies to very shallow depressions that hold water for only a short time in spring (Walker and Coupland, 1970). Approximately 14% of Canada's land area consists of wetlands, which accounts for 24% of all the world's wetlands (Gregorich et al., 2000). Collectively these potholes provide valuable wetland habitat for waterfowl in North America, and are used extensively by a wide diversity of wildlife, providing significant feeding, reproductive and cover habitat (Smith et al., 1964; Toburen and Windell, 1977; Gregorich et al., 2000).

In the prairie pothole region, wetlands and surrounding areas are often unique biodiversity oases, completely surrounded by agricultural monocultures (Usher and Scarth, 1990). In addition to increasing biodiversity, pothole wetlands also offer numerous benefits to agriculture, such as flood control, ground-water recharge, moderating arid climates and providing habitat for a variety of vertebrates and

invertebrates that control weeds and agricultural pests (Martin and Hartman, 1987; Usher and Scarth, 1990).

With regards to practicing sustainable agriculture in this region, one of the areas in need of improvement is wetland protection. One of the barriers to wetland protection in the prairie pothole region is the widespread practice of annual cultivation around wetland areas, which has posed threats such as drainage and land clearing, exotic plant invasion, sedimentation, increased nutrient loading, and pesticide presence (Environment Canada, 1998). In drought years, wetlands are often cultivated and cropped; these same areas often pose problems for cultivation in wetter years (Rickerl et al., 2000). Up to 70% of prairie wetlands have been drained for agriculture, many of which are now only marginally productive under annual crop management (Environment Canada, 1998).

Figure 1.1: Prairie Pothole Region. Adapted from Martin and Hartman, 1987.

1.1.1 Annual Cultivation in Marginal Areas

Annual cultivation is often imposed in wetland areas and other marginal areas due to thin profit margins and the rising costs of operating a competitive farm. Annual cultivation can lead to physical deterioration of the soil due organic matter loss, pulverization of the soil and compaction (Bregha et al., 1990; Mapfumo et al. 2000), especially in marginal areas. Cultivation leaves the soil bare for a period of time, during which it is susceptible to erosion and organic matter loss (Huffman, 2000; Grant et al., 2001). Soils near wetland edges generally consist of deep A horizons rich in organic matter. Cultivation of these areas increases the amount of soil carbon oxidized, which can reduce biomass production and decrease overall productivity (Broersma, 1991). As a result of annual cultivation in Canada, approximately 1 billion tonnes of soil organic carbon have been lost (Bruce et al., 1998).

The use of heavy agricultural machinery can cause compaction of soils (Borchert, 1988; Naeth et al., 1991; Douglas, 1994), which can be even more problematic around wetland margins. Compaction is often exacerbated under wet conditions because moist soils may be compacted deeper than normal tillage depths of 20-30 cm (Naeth et al., 1991). The resulting reduction in pore space, aeration, soil water and permeability leads to decreases in agricultural productivity (Panayiotopoulos et al., 1994).

Annual cropping systems may also leave the soil vulnerable to erosion, which is of special importance in wetland areas. Cultivation pulverizes the soil particles, weakening the soil structure (Mapfumo et al. 2000). These weakened soils are then more susceptible to wind and water erosion, and may find their way into wetlands, degrading the water quality (Martin and Hartman, 1987).

One of the main water quality problems associated with annual cultivation in the prairie pothole region is the increase in sedimentation (Neely and Baker, 1989). With conventional tillage systems (annual cultivation), crops are harvested yearly and the soil is then cultivated in preparation for the following year. Reduced vegetation cover allows for increased runoff and sedimentation due to decreased hydrologic roughness and the increased amount of bare soil available for transport. Because approximately 80% of the water in wetlands comes from direct runoff, sediments and nutrients from the surrounding agricultural land find their way into the wetland (Rickerl et al., 2000). The potential impacts of increased sedimentation on wetlands include the modification, reduction and eventual elimination of wetland habitat through the filling of potholes, as well as contamination due to transport of nutrients, pesticides and other contaminants bound to the sediment (Martin and Hartman, 1987; Neely and Baker, 1989). The transport of sediment-bound nutrients into wetlands can lead to eutrophication (Van der Valk et al., 1978; Jacobs and Gilliam, 1985; Sharpley, 1992). Eutrophication degrades wetland water quality and restricts water use because of undesirable increases in aquatic plant and algae growth, which results in increased biological oxygen demand and potential oxygen shortages (Van der Molen et al., 1998; Sharpley et al., 2000).

1.1.2 Wetland Margins and Conservation

Conserving wetlands is a critical step in practicing sustainable agriculture in the prairie pothole region. It is a landscape-scale endeavor, encompassing not only the wetland basin, but also the wetland margins and associated uplands (Patterson, 1994). Wetland margins are important areas as they influence habitat complexity, biodiversity as

well as energy and nutrient flows (Gregory et al., 1991). As a zone that is important for both agricultural production and ecological conservation, the wetland and the adjacent cropland directly surrounding the wetland (i.e., the *wetland-cropland ecotone*) is one of the most obvious areas in which to concentrate conservation efforts. Careful management of wetland margins offers a strategy for protecting wetland water quality while allowing agricultural land use to continue over the broader landscape.

1.2 The Wetland-Cropland Ecotone

"An ecotone is a zone of transition between adjacent ecological systems having a set of characteristics uniquely defined by space and time scales and by the strength of the interactions between the adjacent ecological systems" (Holland, 1988). Vegetation within ecotones generally experiences a more rapid directional spatial change than vegetation on either side of the ecotone (Lloyd et al., 2000). The wetland-cropland ecotone (Figure 1.2) is a zone of overlap between cropland and wetland, and as such, is a complex area where gradients in water regime (Walker and Coupland, 1968; Millar, 1969), salinity (Bolen, 1964; Dodd and Coupland 1966), soil texture and soil organic matter (Kadlec, 1962; Dale, 1964; Spence, 1967), and disturbance exist (Stewart and Kantrud, 1969). These gradients can influence the distribution of plant species (McNaughton, 1985). With the exception of soil texture and organic matter, these conditions may not only vary from year to year, but also throughout the growing season, depending on snowmelt, precipitation, evaporation and the amount and type of disturbance imposed within an area. The variability in these areas can make for inconsistent and uncertain annual crop performance from year to year.

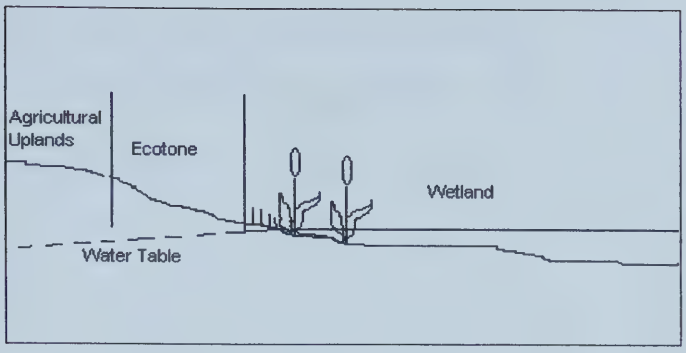


Figure 1.2: Generalized diagram of the ecotone between wetlands and agricultural uplands.

1.2.1 Salinity and Moisture Gradients Within the Ecotone

Of the numerous gradients that exist within these ecotones, it is thought that salinity and water regime have the largest impact on plant growth. According to Walker and Coupland (1970), the type of vegetation found in wetland-cropland ecotones showed very definite relationships along salinity gradients and water regimes, but showed no correlation with size of wetland, surrounding topography, soil texture, organic matter content or water-holding capacity. According to Ungar (1998), factors such as salinity and flooding are considered to be the determining factors controlling vegetation establishment and zonational patterns of species across salt-affected habitats.

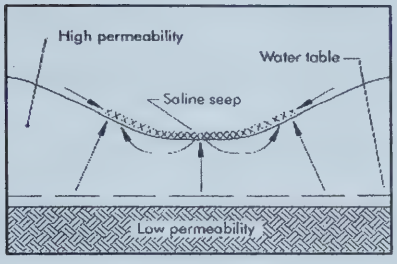
Both salinity and moisture gradients can pose unique challenges that affect the degree of agricultural success. In wet years this area may be difficult to farm because of excess soil moisture (Rickerl et al., 2000). Heavy agricultural machinery may become mired in waterlogged soil, and cultivation may become impossible (Richardson et al., 1994). In dry years, evaporation from the soil surface brings salts into the rooting zone, which increases salinity of the wetland and surrounding area to the point of inhibiting crop growth (Richardson et al., 1994).

1.2.2 Soil Salinity in the Prairie Pothole Region

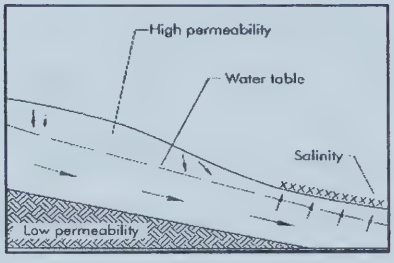
Soil in the prairie pothole region often contains naturally elevated levels of water-soluble salts. The most recent period of glaciation exposed vast amounts of bedrock, which as it weathers (oxidizes), results in material with relatively high concentrations of sulfate salts (Hendry et al., 1986; Keller and Van der Kamp, 1988), the most common of which are sodium and magnesium sulfates (Greenlee et al., 1968; Keller and Van Der Kamp, 1988; Eilers et al., 1995). According to Keller and Van der Kamp (1988) only a small proportion of the total available sulfate has been flushed out of the system in the prairie region since deglaciation approximately 10,000 years ago; much of the remaining sulfates are still within the soil profile and underlying parent material. Most of the affected soils are medium-textured and are next to small wetlands or sloughs and in drainage courses and depressions (Eilers et al., 1995). Through the process of salinization, these salts may become concentrated in the plant root zone, and once elevated, can restrict plant growth and reduce crop yields.

The most common types of dryland (land that is not irrigated) salinity occurring around wetland areas in central Alberta include depression bottom salinity, contact salinity and slough ring salinity (Wentz, 2003a) (Figures 1.3 a, b, c). Depression bottom salinity occurs in rolling or hummocky areas where water flows over the ground surface and ponds in low-lying areas. Ground-water at the edge of the pond moves upslope through the upper soil layer and rises to the soil surface via capillary action and evaporates, leaving any salts on or near the soil surface (Wentz, 2003a). Contact salinity occurs where ground-water flows through a permeable layer that lies above an impermeable or less permeable layer, until the more permeable layer decreases in depth.

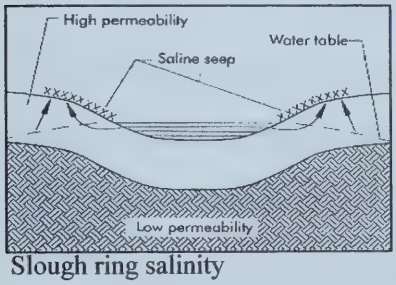
The ground-water is then forced to flow close to the soil surface where it evaporates leaving the salts behind (Wentz, 2003a). Slough ring salinity occurs as a salt ring immediately around a permanent water body. As in depression bottom salinity, some of the water moves into the upper soil layer, rising to the soil surface where it evaporates leaving a ring of salt around the water body (Wentz, 2003a).



a. Depression bottom salinity



b. Contact salinity



c. Slough ring salinity

Figure 1.3 a-c: Depression bottom, contact, and slough ring salinity. From Wentz and King, 1999.

1.2.3 Perennial Forages in Saline Flood-Prone Areas

Salinity is considered to be one of the greatest threats to crop production in many parts of the world (Noaman, 2000), with marked decreases in growth at higher salt concentrations (Phleger, 1971; Ulery et al., 1998). Salts in the soil lower the solute potential of the external solution; the plant must overcome increased water potential gradients if it is to survive (Sanderson et al., 1997). Plants may cope with salinity stress

in a variety of ways, including accumulating, extruding or diluting ions and by selective ion absorption (Howes Keiffer and Ungar, 1997; Sanderson et al., 1997).

Eilers et al. (2000) suggest that land under permanent cover (perennial vegetation) is at the lowest risk for increasing salinization because plants are in place throughout the year, thereby capturing soil water that may otherwise carry salts to ground-water discharge areas. Perennial plants are generally thought to tolerate salinity better than annual plants (Wentz, 2001), and according to McKenzie and Najda (1992), salt tolerant forages are the best-adapted crops for cultivated saline areas.

Alberta Agriculture recommends planting salt and flooding tolerant perennial forages into saline ground-water discharge areas in order to limit expansion of saline seeps (Wentz, 2003b). The following species have been suggested for use in areas with medium to very high salinity (electrical conductivities ranging from 6-12 dS/m): Meadow Foxtail, Smooth Bromegrass, Meadow Bromegrass, Intermediate Wheatgrass, Pubescent Wheatgrass, Creeping Foxtail, Slender Wheatgrass, Tall Wheatgrass, Western Wheatgrass, Russian Wild Rye, Altai Wild Rye, Beardless Wild Rye and Nuttall's Alkali Grass (Wentz, 2003b). All of the above species reportedly have at least medium flooding tolerance, with the exception of Russian Wild Rye, which has poor flooding tolerance (Wentz, 2003b). It is recommended that the salt tolerant vegetation be planted in an area larger than the visibly saline area for better control (Wentz, 2003b).

1.3 Managing the Ecotone as Part of Sustainable Agriculture

Vegetation spatial patterns, species composition and diversity within wetland-upland ecotones are determined by environmental constraints such as salinity, flooding, topography, etc., and are closely linked to variation within the system (Carter et al, 1994;

Perelman et al., 2001). In natural or undisturbed wetland ecotones, plant species will often form concentric rings of distinctive vegetation radiating outward from the wetland based on tolerance to moisture and salinity gradients. Utilizing a similar approach to manage the wetland-cropland ecotone in the prairie pothole region may prove more successful than traditional approaches.

1.4 Anticipated Benefits of Using a Land-Based Approach Within the Ecotone

Wetland margins can be difficult areas to farm due to waterlogging, salinization, soil erosion and the tendency of wet soils to compact. Using a land-based approach in managing the ecotone (e.g. growing salt and flooding tolerant vegetation in saline and flooding prone areas) will increase the likelihood of agricultural success, as land-based management uses not only climate and economic factors as a basis for selecting crops for certain areas, but also uses inherent soil characteristics to determine which crops to grow where.

In order to use a land-based approach to managing the ecotone, it must first be realized that because the ecotone is an area that experiences variation in moisture levels and salinity, plants used within these ecotones must be expected to tolerate fluctuating levels of both. Growing specially selected flood and salt tolerant perennial grasses and legumes in these areas as a vegetated buffer strip around the wetland will likely have many benefits, many of them meeting the objectives of sustainable agriculture. Implementing a permanent vegetated buffer strip consisting of several selected salt and flooding tolerant perennial forages will likely:

a. Enhance water filtration capacity thereby protecting wetland water quality.
b. Control soil erosion.
c. Provide a source of forage.
d. Minimize economic and labor costs for the landowner.
e. Increase local vegetative diversity.
f. Provide wildlife habitat.
g. Minimize soil organic matter loss.
h. Decrease the risk of salinization.
i. Maximize the likelihood of plant establishment and success in a variable, sometimes inhospitable area.
j. Provide increased C-sequestration potential.

1.4.1 Establishing a Permanent Vegetated Buffer Strip

Vegetated buffer strips have been defined as an area of vegetation designed to remove pollutants and sediment from surface water runoff by filtration, deposition, absorption, adsorption, decomposition and volatilization (Dillaha et al., 1989). In saline wetland-cropland ecotones, crop cover is often patchy, with bare soil often visible. This bare soil is available for erosion and transport into the wetland, which may cause sedimentation and/or eutrophication, thus degrading wetland water quality. By using a variety of specially selected salt and flooding tolerant perennial forages as a buffer strip around the wetland, ground cover is increased which protects the soil from further salinization, erosion and organic matter loss.

Increasing ground cover is vitally important in protecting the soil from further salinization because it reduces evaporation and the subsequent rise of salt water by capillary rise to the surface of the discharge area (Eilers et al., 2000). Additionally, if plants can be established in these saline discharge areas, the water table may eventually be lowered, thereby preventing salts from being brought up to the surface. Over time, precipitation events will wash salts out of the rooting zone, eventually leading to a reduction of the salt problem, allowing for a greater variety of plants to be grown in the area.

Vegetated buffer strips attenuate nutrients and sediments by increasing the hydrologic roughness of the ground surface. The vegetation decreases the velocity of runoff water and causes deposition of sediments as well as any sediment-bound nutrients or pesticides while protecting the mineral soil from the erosive power of raindrops (Hewlett, 1982; Barfield et al., 1998). In preventing or reducing erosion, the loss of soil organic matter is also minimized (Huffman, 2000). The concentration of fertilizers and pesticides entering the wetland may be reduced because as the runoff water moves through the strip, the chemicals are adsorbed onto the litter, vegetation and surface soil, where they are later transformed or taken up by the vegetation (Barfield et al., 1998). Because sediments and sediment-bound nutrients are prevented from entering the wetland, siltation and eutrophication risks to the wetland are greatly reduced (Rickerl et al., 2000).

Many studies in the United States have tested the effectiveness of vegetated buffer strips to filter and reduce nutrient inputs and sediment into wetlands and other surface waters. Sediment trapping efficacy of vegetated buffer strips has been shown to be frequently greater than 90%, depending on factors such as particle size, slope steepness

and vegetation density (Barfield and Albrecht, 1982; Hayes and Harriston, 1983; Hayes et al., 1984; Dillaha et al., 1989; Osborne and Kovacic, 1993; Antonius, 1999). The results for nutrient absorption are much more variable, and are very dependent on the width of the filter strip (Pearce et al., 1997; Barfield et al., 1998). According to the results presented in the review section of Barfield et al. (1998), the effectiveness of grassed buffer strips at trapping phosphorus in narrower filter strips (4.6 m) ranged from 6-75%, whereas the trapping efficiency of nitrogen for the same strips ranged from actually releasing 15% more N than was applied, to removing 61% (Dillaha et al., 1989; Magette et al., 1989). Wider filter strips had correspondingly higher trapping efficiencies, where filter strips of 9.1 and 9.2 m had a phosphorus trapping range from 20-80%, and nitrogen trapping range from 35-61% (Dillaha et al., 1989; Magette et al., 1989). In general, wider filter strips are more effective in trapping sediments and nutrients (Bernard et al., 2000).

One of the most common problems associated with vegetated buffer strips cited in much of the literature is that although they may remove nutrients during the growing season, they may release them during the dormant season or if they become saturated (Osborne and Kovacic, 1993; Pearce et al., 1997; Barfield et al., 1998). Selective harvesting of grass buffer strips helps to maintain an intermediate successional state which may enhance the nutrient filtering capacity (Osborne and Kovacic, 1993) while supplying economic gain to the landowner in the form of baled forage.

While there have been numerous studies done in order to test the efficacy of vegetated buffer strips, there has been little research on selecting the most appropriate plant species for the strip based on the characteristics of the land where the strip was to be

implemented. Pure stands of orchardgrass (Thompson et al., 1978; Young et al., 1980; Dillaha et al. 1988; Dillaha et al. 1989), fescue spp. (Doyle et al., 1977; Magette et al., 1989), reed canary grass (Osborne and Kovacic, 1993), kentucky blue grass (Pearce et al., 1997), corn (Young et al., 1980) and oats (Young et al., 1980) as well as mixtures of sorghum and sudangrass (Young et al., 1980) and bermuda and crabgrass (Parsons et al., 1991) have all been used as vegetated buffer strips with varying degrees of success. However, it appears that the species used were not selected for a particular location or reason (the rationale, if there was any, for utilizing the chosen species or mixture was not mentioned in the above literature).

Because marked fluctuations in soil salinity and flooding govern the development of plant communities, resulting in distinct vegetation zones (Rozema and Blom, 1977), it is thought that by using land-based management (selecting the most appropriate plant species for the area) in order to develop the permanent vegetated buffer strips, the benefits of each (land-based management and buffer strips) will be magnified for greater success in protecting the wetland, providing biomass for forage, controlling soil erosion, etc.

Using perennial forages around wetlands can reduce input and labor costs incurred by the landowner. The necessity of continually traveling around wetlands with farm machinery increases production costs and reduces the efficiency of tillage operations (Leitch, 1989). By implementing perennial forages as a buffer strip, the number of passes required around the wetland is decreased, because unlike annual cropping systems, the perennial buffer strips are not seeded every year. Furthermore, they likely do not require fertilization because they will receive inputs in the form of runoff from the upland

agricultural areas, and they are not cultivated annually. One of the goals of sustainable agriculture is to close the loop on nutrient use (Rickerl et al., 2000). Capture and uptake of nutrients within the buffer strip not only prevents them from entering the wetland and potentially deteriorating water quality, but also allows inputs to be utilized at the farm level (minimizing economic loss), because once nutrients and sediments find their way into the wetland they are essentially removed from the agricultural system (Rickerl et al., 2000).

Another goal of practicing sustainable agriculture is to maintain and promote biodiversity (Vandermeer and Perfecto, 1997; Rickerl et al., 2000). Conversion of undisturbed land to agriculture has contributed to declining wildlife habitat and therefore a reduction in wildlife species, mainly through changes in land use, such as drainage of wetlands and removal and fragmentation of forest cover (Neave et al., 2000). Agriculture can affect the quality of wildlife habitat through land management practices such as tillage, fertilization, pesticide use and intensive grazing (Neave et al., 2000). Because there is a large percentage of land devoted to agriculture, practices that enhance habitat on farms could have associated benefits for wildlife (Rodenhouse et al., 1995; Maisonneuve and Rioux, 2001). Using perennial forages instead of annual crops as a buffer zone around the wetland will decrease the disturbance in the area, which increases the suitability of the area as wildlife habitat. Deferring harvest of perennial forages grown within the ecotone can further increase the nesting success of waterfowl by protecting eggs and young birds from machinery (Wark et al., 1995; Jefferson et al., 1999). By using a community of several agronomically valuable salt and flooding tolerant plant species within the ecotone instead of a single annual crop, it is more likely

that at least one of the plant species will be able to tolerate the current conditions. A more complex plant community will also increase overall plant biodiversity of the area, which in turn can lead to increased microbial, fungal and animal diversity due to more diverse habitats and food sources.

1.4.2 Carbon Sequestration

One of the many ways suggested to reduce the amount of carbon dioxide in the atmosphere is to increase the amount of carbon stored within the earth's biota and soil (Smith et al., 2000). Wetlands and surrounding riparian areas have the greatest carbon density of all terrestrial ecosystems (NATO, 1995). According to Environment Canada (1998) there are 2 main attributes of wetlands that may render them net sinks of carbon:

1. High primary productivity, which ensures abundant organic carbon available for sequestration.
2. Reduced decomposition due to the anaerobic nature of wetland sediments.

In order to maintain their function as active carbon sinks, it is essential to prevent degradation and conversion of wetlands (Environment Canada, 1998). Research by Euliss et al. (1999) indicates that pristine (non-farmed) wetlands store twice as much carbon as wetlands that have been drained and converted for agriculture. As mentioned earlier, approximately 70% of prairie wetlands have been drained for conversion to agriculture (Environment Canada, 1998). In order to prevent further drainage or conversion of wetlands, agricultural/economic benefits must be realized by the landowner.

According to Campbell et al. (1991) and Bremer et al. (1994), using perennial crops and legumes can increase the amount of carbon sequestered in soils. Using selected salt and flooding tolerant perennial forages in saline flooded areas will contribute to increased above and below ground biomass production because perennial plants have the ability to develop larger root systems than annual crops. Additionally because the selected forages will be more salt tolerant, with increased survival and biomass over non-selected crops, they provide the opportunity to sequester more carbon.

1.5 Objective of Thesis

Our attempts to "manage" natural resources in the past have often failed over the long term because land managers and policy makers typically focus on one component of the resource, and forget about the complexity of the entire ecosystem, including the interactions between biological, social and financial components of the resource (Savory, 1988). The overall objective of this thesis was to screen agriculturally valuable plants in the greenhouse for tolerance to salinity and flooding in an attempt to find forage species suitable for use in permanent vegetated buffer strips within wetland-cropland ecotones prone to salinity and flooding.

In order to meet the main objective, the project consisted of three related experiments completed in the greenhouse. Numerous grass and legume species were first tested for their ability to germinate under increasing salt concentrations. Species with the greatest germination rates were then grown in the greenhouse and were subjected to increasing salt concentrations and increasing flooding durations. The two most salt tolerant species were then tested further for salinity and flooding tolerance in three soils

of different textures. As a final step, species with highest germination rates under saline conditions were grown together in soil collected from a saline wetland-cropland ecotone, and were subjected to flooded conditions for up to four weeks. The information gathered in this project can be used to further develop a strategy of land-based ecotone management that can be implemented in the field. The premise of the overall strategy takes into consideration not only environmental aspects, but also economic and social aspects of sustainable agriculture, thereby increasing the chance of long-term success.

This thesis has been divided into 5 chapters, where chapter 1 is a general introduction into the concepts of sustainable agriculture, land-based management, wetland-cropland ecotones and the use of buffer strips to protect wetland integrity. Chapter 2 focuses on testing numerous agriculturally valuable plant species for their ability to germinate, and then tolerate increasing levels of salinity and flooding as part of the screening to find plant species suitable for use in buffer strips to protect wetland water quality. The experiment completed in chapter 3 uses the two most salt tolerant forages found in the previous chapter, in order to determine if there is an additive effect of soil texture on the ability to tolerate saline flooded conditions. In chapter 4, the species tested in chapter 2 are tested again for salinity and flooding tolerance, but this time in soil collected from a natural saline wetland-cropland ecotone as an intermediate step before field implementation. Chapter 5 summarizes the information from the 3 experiments and provides some general conclusions and provides recommendations for future research.

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2. The Combined Effects of Salinity and Flooding on the Biomass of Different Forage Species

2.1 Introduction

As part of practicing sustainable agriculture within the prairie pothole region, it is thought that planting selected perennial forages as a buffer strip within the wetland-cropland ecotone for harvest may protect wetlands from agricultural inputs (silt, pesticides and fertilizers), while still allowing the landowner to obtain economic benefit from the forage production. This transition zone from agricultural uplands to the wetland is a complex area, where gradients in both salinity and moisture may exist (Bolen, 1964; Dodd and Coupland 1966; Walker and Coupland, 1968). Perennial forages used within this area must be expected to tolerate a range of salt and soil moisture, as these conditions are not constant but change throughout the growing season as well as from year to year.

Salt affected soils have a deleterious effect on most agricultural plant species, causing decreases in crop yields (Ulery et al., 1998). Increased soil salinity lowers the solute potential of the external solution, presenting plants with increased water potential gradients to overcome, which can reduce germination, stand establishment and yield in forage grasses and legumes (Sanderson et al. 1997). Wetland-cropland ecotones within the prairie pothole region are often affected with varying levels of sodium and magnesium sulphate salts (Greenlee et al., 1968; Keller and van der Kamp, 1988; Eilers et al., 1995), as well as fluctuating water levels due to spring melt and cycles of drought. Forages suitable for use in saline wetland-cropland ecotones in the prairie pothole region must be able to germinate and produce reasonable amounts of biomass when exposed to the most common salts in the area, and should be able to tolerate a range of saline

conditions (from non-saline to strongly saline) as measured by soil electrical conductivity (EC) (from less than 2 dS/m in non-saline areas to over 12 dS/m in strongly saline areas (Wentz, 2003)).

Flooded conditions within the wetland-cropland ecotone due to snowmelt in the spring or excessive precipitation can lead to waterlogging and hypoxia. Under waterlogged conditions, the soil becomes oxygen deficient due to reduced gas exchange rates at the soil surface, which in turn can lead to reductions in root and shoot growth, dry matter accumulation and total yield (Drew, 1991; Lessmann et al. 1997). The growth of many flood tolerant species may be reduced when roots are waterlogged, but unlike flooding sensitive species, they rapidly improve once aeration is restored (Crawford, 1982).

While there has been extensive research on the ability of many different plants to tolerate salt and some research on the ability of plants to tolerate hypoxic conditions, there has been considerably less documentation of research focusing on the combined effects of both flooded and saline conditions. In trying to find suitable forages species for the wetland-cropland ecotone, it is important to study both factors together as soil salinity and root zone hypoxia caused by flooded conditions in combination may damage agricultural plants and depress growth more than either factor alone (West and Taylor, 1980; Galloway and Davidson, 1993). The majority of the salinity and waterlogging studies cited in the literature focus on either sodium chloride or diluted seawater, not on sodium and magnesium sulfates (common salts in the prairie pothole region).

The objective of this study was to determine the range of salt (sodium and magnesium sulfates) and flooding tolerance of numerous forages for possible use within

the wetland-cropland ecotone, as well as to determine optimal planting locations for selected species within the ecotone buffer zone based on observed tolerance. The forages were first screened for ability to germinate under increasing levels of salt. The species with the greatest germination rates overall and under the highest salt concentration were further tested in the greenhouse for tolerance to a range of saline flooded conditions.

It was hypothesized that all the plant species would decrease in survival, above and below ground biomass when exposed to increasing levels of salt and increasing durations of flooding. It was further hypothesized that some species would exhibit increased salt and flooding tolerance, and thus be more suitable candidates as part of a vegetated buffer strip.

2.2 Methods

Generally, increasing levels of salinity reduce seed germination and seedling emergence (Sanderson et al., 1997); according to many researchers, germination is more sensitive to salinity stress than is the growth of established plants (Freeman, 1973; Hausenbuiller,1985; Catalán et al., 1994; and Puppala et al., 1999). For this reason, in order to maximize the number of plant species tested, commercially available forage species were first screened for their ability to germinate under increasing salinity ranging from 0-12 dS/m before further testing their tolerance to salt and flooding.

Due to a lack of greenhouse space, both components of this experiment (germination and biomass production) were run twice, where each trial was run with a different set of plant species. Although the second trial of each component was carried out in a similar manner to the first, the results cannot be compared directly because each

trial was not exposed to exactly the same conditions. The first germination trial was started in November and the first biomass trial was started in December; supplemental light supplied by sodium halide light bulbs was used to augment light intensity for the entire photoperiod of 16 hours as the day length was relatively short. The second germination trial was started in April, and the second biomass production trial was started at the beginning of June when day length is nearing the maximum. In the second trials, because of higher intensity natural light, supplemental light was only used when necessary to increase the photoperiod to 16 hours. Also, temperatures within the greenhouse were not consistent over the two trials, mainly because of an inadequate cooling system. In the summer months, the daytime temperatures were often considerably higher than in the winter months. As a result of these inconsistencies between trials, instead of comparing the results from the two trials directly, all species used in the two biomass trials were used and compared directly in another experiment where they were grown together in the greenhouse in soil collected from a natural saline wetland-cropland ecotone (chapter 4).

2.2.1 Germination Component

2.2.1.1 Species Selection

In order for a particular forage species to be used in the germination component of this experiment, it had to satisfy a number of requirements. All species used had to be commercially available, as well as satisfy at least three of the following criteria:

1. Commonly used forage within the prairie pothole region of Alberta.
2. Reported flood tolerance.

3. Reported salt tolerance.
4. Potential for wildlife use.
5. Potential for hay use.

Twenty-two different species satisfied the above requirements and were used in the germination component of this experiment. As mentioned earlier, due to logistical constraints, the germination trial was completed over two separate trials. The first trial included the following species: Smooth Brome (*Bromus inermis* leyss.), Crested Wheatgrass (*Agropyron pectiniforme* R. & S.), Western Wheatgrass (*Agropyron smithii* Rydb.), Northern Wheatgrass (*Agropyron dasystachyum* (Hook.) Scribn.), Slender Wheatgrass (*Agropyron trachycaulum* var. *trachycaulum* (Link) Malte), Alkali Grass (*Puccinellia nuttalliana* (Schulte.) A.S. Hitchc.), Hairy Wild Rye (*Elymus innovatus* Beal), Russian Wild Rye (*Psathyrostachys juncea* Fisch.), Junegrass (*Koeleria macrantha* (Ledeb.) J.A. schultes f.), Orchard Grass (*Dactylis glomerata* L.), Reed Canary Grass (*Phalaris arundinacea* L.), Redtop (*Agrostis stolonifera* L.) and Tufted Hair Grass (*Deschampsia cespitosa* (L.) Beauv.), for a total of 13 different species. The second trial included: Altai Wild Rye (*Leymus angustus* (Trin.) Pilger), Creeping Red Fescue (*Festuca rubra* L.), Timothy (*Phleum pretense* L.), Tall Fescue (*Festuca arundinacea* Schreb.), Bird's-foot Trefoil (*Lotus corniculatus* L.), Alsike Clover (*Trifolium hybridum* L.), Cicer Milkvetch (*Astragalus cicer* L.), Meadow Brome (*Bromus biebersteinii* Roemer & J.A. Schultes) and Alfalfa (*Medicago sativa* L.). Because of fungal contamination problems in trial 1, new seedlots of Slender Wheatgrass, Northern Wheatgrass and Western Wheatgrass were re-tested, for a total 9 species not tested in the first trial.

2.2.1.2 Experimental Design

The experiment was set up as a completely randomized design in a greenhouse with an approximate temperature range of 18° C night and 22° C day and a 16-hour photoperiod in order to compare the germination rates of the 13 and 12 different species (trials 1 and 2, respectively) under increasing levels of sodium and magnesium sulfates (0, 4, 8, and 12 dS/m).

The seeds were obtained from Prairie Seeds (1805-8th Street Nisku, Alberta, Canada) and were surface sterilized with 2% (v/v) sodium hypochlorite (15% household bleach) for 7 minutes and then rinsed three times in sterile water (adapted from Villagra, 1997) in order to reduce incidents of fungal contamination. Autoclaved filter paper was placed in 8.5-cm sterile petri dishes and was moistened with 3 mL of a single treatment solution containing sterile distilled water and $MgSO_4$ and Na_2SO_4 salts in a 2:1 ratio with electric conductivities of approximately 4, 8, and 12 dS/m (adapted from Freeman, 1973; Steppuhn and Wall, 1993) as measured with an Oakton PC 300 series portable pH/ electrical conductivity/ temperature meter (Oakton Instruments 625 East Bunker Court, Vernon Hills, IL 60061, U.S.A.) (Table 2.1). The salts were added in a 2:1 ratio so that the ionic ratio of Mg and Na would be 1:1 in solution. A control of pure sterile distilled water without added salt was also tested. In the first trial of the germination component, only 5 seeds per plate were tested for the 13 species and 4 salt treatments, with 3 replicates of each treatment*species combination for a total of 156 plates, and 15 seeds for each treatment*species combination. In the second trial, 10 seeds per plate were used for each of the 12 species and 4 salt treatments, again with 3 replicates of each

treatment*species combination for a total of 144 plates and 30 seeds for each treatment*species combination.

Table 2.1: EC, pH and the amount of Na_2SO_4 and $MgSO_4$ required to produce treatment electrical conductivities.

Treatment	EC (dS/m)	pH	Na_2SO_4 (g/L)	$MgSO_4$ (g/L)
Control	0.0	7.5	0.00	0.00
4 dS/m	4.0	6.6	1.18	2.00
8 dS/m	8.0	6.6	2.95	5.00
12 dS/m	12.0	6.4	5.31	9.00

Total germination for all species*treatment combinations were calculated after two weeks. For the purpose of experiment 1, if a species had a very poor germination rate, it was not included in subsequent biomass trials. All species used in the subsequent salt and flood tolerance experiments had at least 20% germination at the greatest salt level (12 dS/m) and appeared within the top 6 or 5 species (trials 1 and 2 respectively) for both total germination over all salt levels and germination under the 12 dS/m level. It was important to use species able to germinate under a range of electrical conductivities in the subsequent biomass production trials in order to maximize the opportunity for success in an experiment that seeks to mimic the range of salinity conditions that may be experienced within a natural wetland-cropland ecotone.

2.2.1.3 Statistical Analyses

This experiment was set up as a completely randomized two-factor factorial. The two factors were salt and species; salt had 4 levels (EC of approximately 0, 4, 8 and 12 dS/m), and species had 13 and 12 levels (trial 1 and 2 respectively). Chi-Squared

maximum likelihood analysis of variance was calculated using CATMOD (categorical model) in the SAS 8.0 statistical package (1999). Treatment, species and interaction effects were considered significant at α=0.05. Both species and salt were completely crossed, fixed effects.

2.2.2 Biomass Production Component

Due to logistical constraints, the 11 species that had at least 20% germination at the 12 dS/m treatment level were further tested in two separate biomass trials.

2.2.2.1 Experimental Design

In order to determine if the plants would be able to establish under saline conditions it was necessary to apply increasing salt treatments to the 6 species for 3 months or 5 species for 2 months (trials 1 and 2, respectively). The experiment was set up in a greenhouse with an approximate temperature range of 18° C night and 22° C day and a 16-hour photoperiod. The salt treatments included increasing levels of sodium and magnesium sulfates (0, 4, 8 and 12 dS/m), with twelve replicates for each treatment*species combination (these twelve replicates were further divided into four flooding treatments with three replicates each for the salt*flooding combination for the latter half of the biomass production component). For ease of treatment application and in order to minimize human error, the salt treatments were randomly placed as blocks on the greenhouse bench (72 and 60 pots per block in trials 1 and 2, respectively). The pots containing individual plant species were randomly placed within these salt blocks.

Five-inch (12.7 cm diameter) plastic plant pots with 5 holes in the bottom were used in the first trial; six-inch (15.2 cm diameter) plant pots with 5 holes in the bottom were used in the second trial, with three replicates of each species-treatment combination, for a total of 288 pots in the first trial and 240 in the second. In both trials, the pots were first lined with Weed-Shield® landscape fabric before sieved (710 μm), autoclaved sand was poured into the pots. The five-inch pots contained approximately 0.75 L of sand and the six-inch pots contained approximately 1.5 L of sand. The filled pots were saturated with one of the treatment solutions until the EC of the leachate, measured with the Oakton PC 300 series portable pH/ electrical conductivity/ temperature meter was equal to that of the input solution.

Treatments included a control of half strength Hoagland's solution (Hoagland and Arnon, 1938 as cited in Hewitt, 1966) and three salt solutions consisting of half strength Hoagland's solution (Table 2.2) with added $MgSO_4$ and Na_2SO_4 salts in a 2:1 ratio (adapted from Rogers and West, 1993). The salts were added in a 2:1 ratio so that the ionic ratio of Mg and Na would be 1:1 in solution. Many researchers use Hoagland's solution in the testing of plant salt tolerance, as it includes both macro and micronutrients essential for plant growth (Phleger, 1971; Gallager, 1985; Winicov, 1991; Rogers et al., 1996; Howes Keiffer and Ungar, 1997; Hester et al., 1998; Hamilton et al., 2001). Electrical conductivities of the treatments were approximately 0, 4, 8 and 12 dS/m (Table 2.1). Each pot was then seeded with a single plant species (25 seeds / pot) from the following list, and after the seedlings had emerged, they were thinned to four seedlings per pot for a total of 1152 plants in trial one and 960 plants in trial two.

The first biomass trial included the species with the greatest germination rates from the first germination trial: Crested Wheatgrass, Russian Wild Rye, Tufted Hair Grass, Reed Canary Grass, Redtop and Alkali Grass. Over three months all the pots were watered with 200 mL of one of the three salt solutions or the control when the sand began to dry out (approximately 2-4 times per week). The second trial of the biomass component included the species with the greatest germination rates from the second germination trial: Tall Fescue, Creeping Red Fescue, Alfalfa, Bird's-foot Trefoil and Timothy. Because of larger pots and more favorable growing conditions (better light conditions and higher temperatures), the pots in the second trial were watered with 250 mL of one of the three treatment solutions or the control when required (approximately 2-5 times per week) over two months, instead of 200 mL of treatment solution when required over three months as in trial one. See Table 2.3 for a summary of differences between trial 1 and 2. For both trials, the EC of the leachate was monitored on a regular basis to ensure the salt level of the growing media was within the range for each particular treatment. If the EC increased out of the range of acceptability (+1.0 dS/m), all of the pots were watered with a solution of half-strength Hoagland's solution with deionized water to drop the EC back into the acceptable range (+/- 1.0 dS/m). After three or two months (trial one and two respectively), the establishment phase of the biomass production component was ended. All plants were harvested at 5 cm above the sand surface, and biomass was dried and weighed (data not presented).

After harvesting the biomass from each of the salt trials, the plants were allowed to recover for one week before the pots were put into the cold room at 4°C in order to induce a dormant-like state (no further growth). Pots were watered with sterile distilled

water as they began to dry out. After five weeks at 4°C, the pots were brought back into the greenhouse; the above ground biomass was again trimmed to 5 cm above sand surface so all plants were of equal height, and the flooding trial was started.

This part of the experiment was set up as a split plot design in a greenhouse with an approximate temperature range of 18° C night and 22° C day and a 16-hour photoperiod. The purpose of this part of the experiment was to compare the above and below ground biomass production of the 6 and 5 different species (trials 1 and 2, respectively) under increasing levels of sodium and magnesium sulfates (0, 4, 8 and 12 dS/m), and increasing durations of flooding (saturation up to the sand surface, without free water above the surface for 0, 1, 2 and 4 weeks) with three replicates for each salt*flood*species combination. For this half of the biomass production component, the greenhouse bench was set up into three blocks (replicates), where the block was considered to be the whole plot. Rubbermaid® bins containing salt*flooding treatments, considered as part of the whole plot, were randomly placed within these blocks. Plant species were considered as the sub-plot.

The flooding treatments included a control of 0 weeks, as well as durations of 1, 2 and 4 weeks under flooded conditions with the appropriate salt treatment solution. Pots were separated into 3 replicates for each of the species*salt*flooding treatment combinations, and were then placed in three, 35-L Rubbermaid® bins (one bin for each replicate) containing salt treatment solutions. Each bin contained a single salt solution (0, 4, 8 and 12 dS/m), and all 6 or 5 species (trials 1 and 2 respectively). The pots placed inside each bin were flooded up to the surface of the sand with the appropriate salt treatment. The non-flooded treatments (controls) were watered when dry with the

appropriate treatment solution (0, 4, 8 or 12 dS/m). In order to account for water lost through evaporation and transpiration, water was added to flooded treatments when required in order to maintain EC and flooded conditions up to the soil surface (St. Omer and Schlesinger, 1980). After each flooding treatment was completed, pots were removed from the bins and then watered when required with appropriate treatment solution until all 3 flooding treatments (durations of 1, 2 and 4 weeks) were completed.

Table 2.2: Full Strength Hoagland's solution constituents and concentrations.

Macronutrient Stock Solution	Stock Concentration (g/L)	mL of stock/ L of solution	Final Concentration
KNO_3	101.1	6	6 mM
$Ca(NO_3)_2$	164.1	4	4 mM
$NH_4H_2PO_4$	115.0	1	1 mM
$MgSO_4$	120.4	2	2 mM
Micronutrient Stock Solution		1	1 mM
H_3BO_3	2.9		0.5 mg/L B
$MnCl_2*4H_2O$	1.8		0.5 mg/L Mn
$ZnSO_4*7H_2O$	0.2		0.05 mg/L Zn
$CuSO_4*5H_2O$	0.1		0.02 mg/L Cu
85% Mo acid	0.02		0.01 mg/L Mo
Fe-EDTA	1.0		1 mg/L

Table 2.3: Duration of plant establishment and flooding phases, and differences between trial 1 and trial 2 of the biomass production component.

Factor	Trial 1	Trial 2
Start Date	Dec. 12	Jun. 07
End Date	May 08	Oct. 16
Pot volume	0.75 L	1.5 L
Watering volume	200 mL	250 mL
Duration of plant establishment	12 weeks	9 weeks
Duration of cold storage	5 weeks	5 weeks
Duration of flooding phase	4 weeks	4 weeks
Total trial duration	21 weeks	18 weeks

After the flooding component was completed, the number of plants surviving were counted. All plants (up to four seedlings per pot) were harvested at the sand surface. Roots were washed free of sand and both root and shoot samples were dried at 65° C until biomass reached a constant weight (approximately 48 hours). Biomass of both shoots and roots was measured and recorded. In both trials, species performance was measured as a combination of survival, above ground biomass production, below ground biomass production and root:shoot ratios. Root biomass was expressed as an average calculated by dividing the amount of root biomass by number of survived plants per pot, as it was not possible to separate the roots from each individual plant. Due to the limited amount of above ground biomass produced under many of the treatments, the dried above ground biomass for each of the 4 plants in all three replicates of each species*salt*flooding treatment were combined together and then ground to a 1 mm sieve in a UDY Cyclone Sample Mill (UDY Corporation 201 Rome Court Fort Collins, Colorado, USA 80524) and sent to Norwest Labs (9938-67th Avenue Edmonton, Alberta, Canada) for feed analysis. Analyses completed included: crude protein, acid detergent

fiber, total digestible nutrients, digestible energy, calcium, phosphorus, potassium, magnesium and sodium. Statistical analyses on these results were not possible because all replicates were combined.

2.2.2.2 Statistical Analyses

This part of the experiment was set up as a three-factor factorial, split plot design, with block and the salt*flooding treatments considered as the main plot. The three factors were salt, flood and species; salt had 4 levels (Electrical conductivities of approximately 0, 4, 8 and 12 dS/m), flood had four levels (0, 1, 2 and 4 week durations) and species had 6 or 5 levels (trials 1 and 2 respectively). Block, salt and flood effects (whole plot) were tested with the interaction (block*salt*flood) as the error term. All other effects and interactions (sub-plot) were tested with the natural error term. Probabilities and F-values reported for species and salt are the type III, calculated using the specified error term. Means, LS means, standard errors and ANOVA were calculated using GLM, and the Chi-Squared maximum likelihood analysis of variance was calculated using CATMOD, in the SAS 8.0 statistical package (1999-2000). Normality was tested using the Shapiro-Wilks test within UNIVARIATE (SAS, 1999-2000). Root data was not normally distributed, however transformations did not improve normality. It was assumed that the ANOVA procedure, especially with large sample size was robust enough to handle the data. Post-hoc multiple comparisons of significant response variables and interactions were completed using the Tukey-Kramer adjusted pairwise comparisons of the LS means. Treatment, species and interaction effects were considered significant at $\alpha=0.05$. Species, salt and flood were completely crossed, fixed effects.

2.3 Results

2.3.1 Germination Component

The top 6 species used in the biomass component were determined using the frequency tables (% germination) from the Chi-Squared analysis of greatest level of salt (12 dS/m), as well as over all salts (Table 2.5). Slender Wheatgrass and Western Wheatgrass did not germinate under any treatment, including the control. Consequently, new seedlots were obtained from Prairie Seeds, and both were used again in the second germination trial. Northern Wheatgrass had high rates of fungal infection, even after disinfection, which may have hindered germination success. For that reason, a new seedlot of Northern Wheatgrass was acquired from Prairie Seeds and used in the second trial of the germination experiment.

While increasing levels of salt negatively impacted the germination rates of all the species, 8 of the 13 species used in the trial were able to germinate at 12 dS/m (Table 2.4, Figure 2.1). All 6 species used in the biomass production experiment had a germination rate of at least 20% in the 12 dS/m treatment, and were also included within the top 6 germinators over all treatments (Table 2.5).

As in trial one, germination rates of all the species in trial 2 were reduced under increasing levels of salt (Table 2.7, Figure 2.2), although 8 species of the 12 used in the trial were able to germinate at 12 dS/m. All 5 species used in the second biomass trial had germination rates of at least 20% in the greatest salt treatment, and were also included within the top 5 germinators over all treatments (Table 2.7, Figure 2.2).

As a result of pre-screening species for ability to germinate under high levels of salinity, the number of species tested in the subsequent biomass production trials was

much reduced. Out of the 22 species tested initially, only the following 11 were used in the two biomass trials: Alkali Grass, Crested Wheatgrass, Russian Wild Rye, Tufted Hair Grass, Reed Canary Grass, Redtop, Bird's-foot Trefoil, Alfalfa, Tall Fescue, Creeping Red Fescue and Timothy.

It should be noted that germination rates are a function not only of environmental conditions present, but also of seed quality and vigor. Lower germination rates may not be due to decreased salt tolerance, but could also be caused by poor seedlots. Some of the species tested with poor germination rates are reported to be salt tolerant (e.g. In Wentz (2003), Western Wheatgrass and Slender Wheatgrass are reported to be highly salt tolerant; Meadow Brome and Smooth Brome are reported to have medium salt tolerance). But, for the purpose of the following biomass trial, species with the lowest germination rates were not used.

Table 2.4: Chi-Squared maximum likelihood Analysis of Variance for trial 1 of the germination trial.

Source of Variation	D.F.	Chi-Square	Pr>Chi-Square
Intercept	1	3.62	0.0570
Species	12	103.03	<0.0001
Treatment	3	57.99	<0.0001
Species*Treatment	36	37.84	0.3851

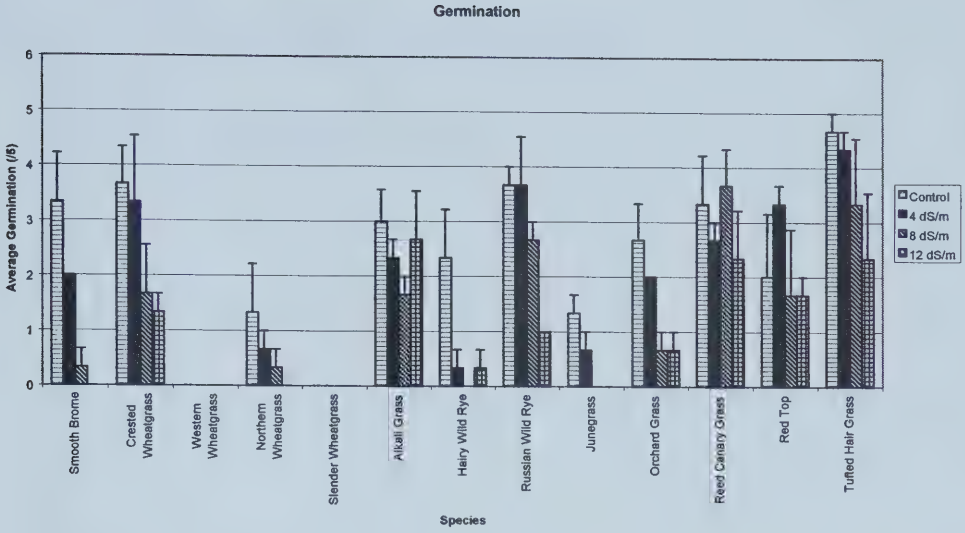

Figure 2.1: Average germination rates for all species at all salt levels tested in germination trial 1. Values are averages of three replicates.

Table 2.5: Number of seeds germinated, germination percentages for each treatment and totals over all treatments in trial 1.

Species	0 dS/m		4 dS/m		8 dS/m		12 dS/m		**Total**	
	#	%	#	%	#	%	#	%	#	%
Tufted Hair Grass	14	93.3	13	86.6	10	66.7	7	46.7	**44**	**73.3**
Reed Canary Grass	10	66.7	8	53.3	11	73.3	7	46.7	**36**	**60.0**
Russian Wild Rye	11	73.3	11	73.3	8	53.4	3	20.0	**33**	**55.0**
Crested Wheatgrass	11	73.3	10	66.7	5	33.3	4	26.7	**30**	**50.0**
Alkali Grass	9	60.0	7	46.7	5	33.3	8	53.3	**29**	**48.3**
Redtop	6	40.0	10	66.7	5	33.3	5	33.3	**26**	**43.3**
Orchard Grass	8	53.3	6	40.0	2	13.3	2	13.3	**18**	**30.0**
Smooth Brome	10	66.7	6	40.0	1	6.7	0	0.0	**17**	**28.3**
Hairy Wild Rye	7	46.7	1	6.7	0	0.0	1	6.7	**9**	**15.0**
Northern Wheatgrass	4	26.7	2	13.3	1	6.7	0	0.0	**7**	**11.7**
Junegrass	4	26.7	2	13.3	0	0.0	0	0.0	**6**	**10.0**
Slender Wheatgrass	0	0.0	0	0.0	0	0.0	0	0.0	**0**	**0.0**
Western Wheatgrass	0	0.0	0	0.0	0	0.0	0	0.0	**0**	**0.0**
Total	**94**	**48.2**	**76**	**39.0**	**48**	**24.6**	**37**	**19.0**	**255**	**32.7**

Table 2.6: Chi-Squared maximum likelihood Analysis of Variance for trial 2 of the germination trial.

Source of Variation	D.F.	Chi-Square	Pr>Chi-Square
Intercept	1	2.25	0.1339
Species	11	326.16	<0.0001
Treatment	3	129.33	<0.0001
Species*Treatment	33	88.73	<0.0001

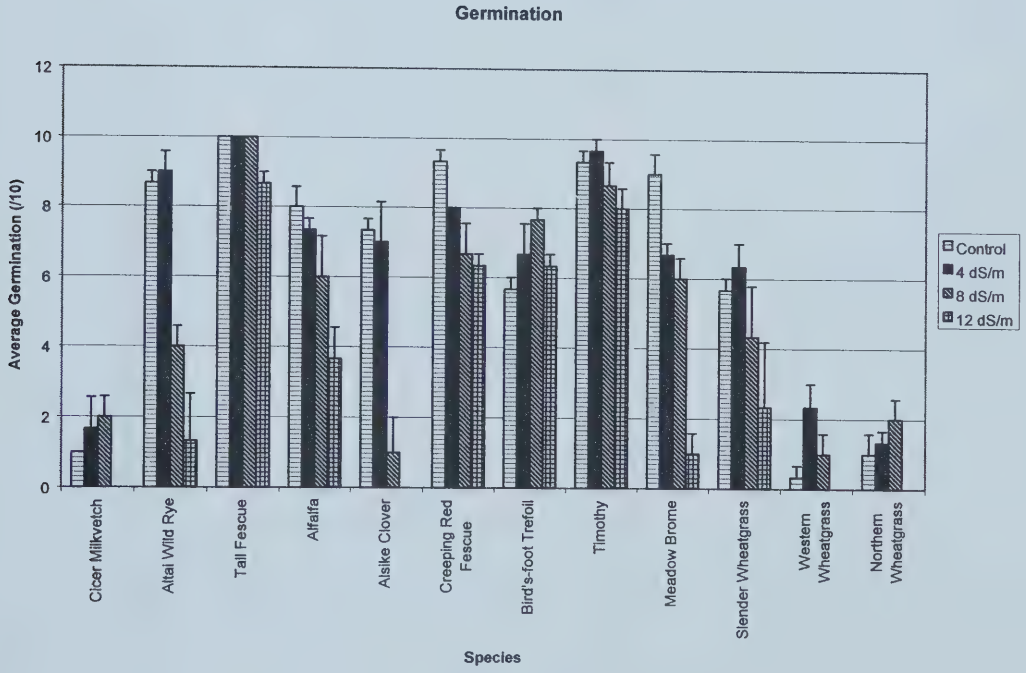

Figure 2.2: Average germination rates for all species at all salt levels tested in germination trial 2. Values are averages of three replicates.

Table 2.7: Number of seeds germinated, germination percentages for each treatment and totals over all treatments in trial 2.

Species	0 dS/m		4 dS/m		8 dS/m		12 dS/m		**Total**	
	#	%	#	%	#	%	#	%	#	%
Tall Fescue	30	100.0	30	100.0	30	100.0	26	86.7	**116**	**96.7**
Timothy	28	93.3	29	96.6	26	86.7	24	80.0	**107**	**89.2**
Creeping Red Fescue	28	93.3	24	80.0	20	66.7	19	63.3	**91**	**75.8**
Bird's-foot Trefoil	17	56.7	20	66.7	23	76.7	19	63.3	**79**	**65.8**
Alfalfa	24	80.0	22	73.3	18	60.0	11	36.7	**75**	**62.5**
Altai Wild Rye	26	86.7	27	90.0	12	40.0	4	13.3	**69**	**57.5**
Meadow Brome	27	90.0	20	66.7	18	60.0	3	10.0	**68**	**56.7**
Slender Wheatgrass	17	56.7	19	63.3	13	43.3	7	23.3	**56**	**46.7**
Alsike Clover	22	73.3	21	70.0	3	10.0	0	0.0	**46**	**38.3**
Cicer Milkvetch	3	10.0	5	16.7	6	20.0	0	0.0	**14**	**11.7**
Northern Wheatgrass	3	10.0	4	13.3	6	20.0	0	0.0	**13**	**10.8**
Western Wheatgrass	1	3.3	7	23.3	3	10.0	0	0.0	**11**	**9.2**
Total	**226**	**62.8**	**228**	**63.3**	**178**	**49.4**	**113**	**31.4**	**745**	**51.7**

2.3.2 Biomass Production Component

Both Bird's-foot Trefoil and Alfalfa had approximately 90% death after the period of induced dormancy. As a result, they were not included in the remaining results.

2.3.2.1 Survival

In trial 1, the survival rates of Crested Wheatgrass, Reed Canary Grass and Tufted Hair Grass were the most negatively impacted by the 12 dS/m treatment of all the species tested, although Reed Canary Grass performed well at the 4 dS/m and 8 dS/m salt levels (Table 2.10). Tufted Hair Grass had the lowest overall survival (over all the treatments) at 66.7 % while Alkali Grass had the greatest overall survival at 100%. Survival rates of Alkali Grass were not significantly affected by any of the salt levels. In trial 2, Timothy had the lowest survival rate of the three species at every salt level, and had only 29.2 % survival at the 12 dS/m level. Creeping Red Fescue had the greatest survival rate at the 0 dS/m level, but Tall Fescue had the greatest level of survival at all other salt treatment levels (Table 2.11).

Table 2.8: Chi-Squared maximum likelihood Analysis of Variance for trial 1 for survival data.

Sources of Variation	D.F.	Chi-Square	Pr>Chi-Square
Species	5	15.59	0.0081
Salt	3	67.06	<0.0001
Flood	3	1.64	0.6496
Species*Salt	15	69.92	<0.0001
Species*Flood	15	24.92	0.0511

Table 2.9: Chi-Squared maximum likelihood Analysis of Variance for trial 2 for survival data.

Sources of Variation	D.F.	Chi-Square	Pr>Chi-Square
Species	2	60.29	<0.0001
Salt	3	20.61	0.0001
Flood	3	7.05	0.0703
Species*Salt	6	44.01	<0.0001
Species*Flood	6	1.35	0.9690

Table 2.10: Number of plants survived, survival percentages for each treatment and totals over all treatments in trial 1.

Species	0 dS/m		4 dS/m		8 dS/m		12 dS/m		**Total**	
	#	%	#	%	#	%	#	%	#	%
Alkali Grass	48	100.0	48	100.0	48	100.0	48	100.0	**192**	**100.0**
Russian Wild Rye	32	66.7	31	64.6	36	75.0	36	75.0	**135**	**70.3**
Red Top	47	97.9	43	89.6	31	64.6	34	70.8	**155**	**80.7**
Reed Canary Grass	44	91.7	42	87.5	42	87.5	23	47.9	**151**	**78.6**
Crested Wheatgrass	47	97.9	45	93.8	33	68.8	19	39.6	**144**	**75.0**
Tufted Hair Grass	39	81.3	37	77.1	29	60.4	23	47.9	**128**	**66.7**
Total	**257**	**89.2**	**246**	**85.4**	**219**	**76.0**	**183**	**63.5**	**905**	**78.6**

Table 2.11: Number of plants survived, survival percentages for each treatment and totals over all treatments in trial 2.

Species	0 dS/m		4 dS/m		8 dS/m		12 dS/m		**Total**	
	#	%	#	%	#	%	#	%	#	%
Tall Fescue	44	91.7	47	97.9	48	100.0	48	100.0	**187**	**97.4**
Creeping Red Fescue	46	95.8	42	87.5	40	83.3	43	89.6	**171**	**89.1**
Timothy	40	83.3	37	77.1	34	70.8	14	29.2	**125**	**65.1**
Total	**130**	**90.3**	**126**	**87.5**	**122**	**84.7**	**105**	**72.9**	**483**	**83.9**

2.3.2.2 Above Ground Biomass

In both trials, as expected, the overall salt effect (obtained by averaging across all flood*species interactions for each salt level) is one where increasing salt levels decreases the amount of overall above ground biomass produced. In trial 1 there is no significant difference in the total amount of above ground biomass produced between salt treatment 1 (0 dS/m) and salt treatment 2 (4 dS/m), but both salt treatment 3 and 4 (8 dS/m and 12 dS/m) experience significant decreases in above ground biomass production when compared to salt treatment 1 and 2 (Figure 2.3). Salt treatment 4 produced significantly less above ground biomass than did salt treatment 3. In trial 2, there was no significant difference in the total amount of above ground biomass produced between salt treatment 2 (4 dS/m), and salt treatment 3 (8 dS/m) but these treatments did experience significant decreases in above ground biomass production when compared to salt treatment 1 (0 dS/m) and produced significantly more above ground biomass than did salt treatment 4 (12 dS/m) (Figure 2.4).

In both trials, the overall flood effect, obtained by averaging across all salt*species interactions for each flood level shows that only flood treatment 4 (a duration of 4 weeks) produced significantly different amounts of above ground biomass than the other treatments. The amount of biomass produced under four weeks of flooding was greater than that produced at all 0, 1 and 2 weeks of flooding (Figures 2.5 and 2.6).

In trial 1, the overall species effect, obtained by averaging across all treatment levels for each species, shows that Russian Wild Rye produced significantly less above ground biomass when compared to all other species. The other species did not produce significantly different amounts of above ground biomass (Figure 2.7). In trial 2, the

overall species effect, obtained by averaging across all treatment levels for each species, shows that both Creeping Red Fescue and Timothy produced significantly less above ground biomass than Tall Fescue, although they did not produce significantly different amounts of above ground biomass from each other (Figure 2.8).

When comparing the salt effect on each of the different species in trial 1 (the salt*species interaction), obtained by averaging across all flood levels, it was interesting to note that while all other species experienced significant decreases in above ground biomass production with increasing salt levels (from the 0 and 4 dS/m treatment level to the 12 dS/m level), both Alkali Grass and Russian Wild Rye did not show a significant decrease (Figure 2.9). Alkali Grass produced significantly more above ground biomass at the 12 dS/m treatment level than both Russian Wild Rye and Tufted Hair Grass. The differences between all other species at the 12 dS/m level were not significantly different.

When comparing the salt effect on each of the different species in trial 2, all three species experienced significant decreases from the 0 dS/m treatment level to the 12 dS/m level (Figure 2.10). There were no significant decreases from the 0, 4 and 8 dS/m treatments for Tall Fescue. Timothy experienced significant decreases in above ground biomass from the 0 to 4 dS/m treatment levels and again from the 4 to 12 dS/m treatment levels. Creeping Red Fescue experienced significant decreases in biomass from the 0 to 8 dS/m and 12 dS/m levels. Tall Fescue produced significantly more above ground biomass at the 4, 8 and 12 dS/m treatment levels than both Timothy and Creeping Red Fescue. No difference existed between Creeping Red Fescue and Timothy at the 12 dS/m level. When comparing the effect of increasing flooding durations on each of the different species in trial 2 (the flood*species interaction), obtained by averaging across all salt

treatments, none of the species showed significant differences in above ground biomass production throughout the 0 weeks, 1 week or 2 weeks of flooding (Figure 2.11). Creeping Red Fescue showed no significant difference throughout the entire 0 through 4 weeks of flooding. After both 2 and 4 weeks of flooding, Tall Fescue produced significantly more biomass than both Timothy and Creeping Red Fescue. At four weeks of flooding, Timothy produced significantly more above ground biomass than at 0 weeks, and Tall Fescue produced significantly more biomass at 0 weeks than at the other flooding durations.

Table 2.12: Analysis of Variance for trial 1 for above ground biomass data Type III SS.

Sources of Variation	D.F.	F Value	Pr>F
Block	2	7.43	0.0024
Salt	3	48.99	<0.0001
Flood	3	11.45	<0.0001
Error = Block*Salt*Flood	30	0.56	0.9720
Species	5	14.62	<0.0001
Salt*Species	15	3.47	<0.0001
Flood*Species	15	1.58	0.0727
Salt*Flood*Species	45	0.58	0.9869

Table 2.13: Analysis of Variance for trial 2 for above ground biomass data Type III SS.

Sources of Variation	D.F.	F Value	Pr>F
Block	2	5.68	0.0081
Salt	3	20.61	<0.0001
Flood	3	12.13	<0.0001
Error = Block*Salt*Flood	30	1.36	0.0994
Species	2	73.81	<0.0001
Salt*Species	6	3.83	0.0010
Flood*Species	6	4.03	0.0006
Salt*Flood*Species	18	0.92	0.5548

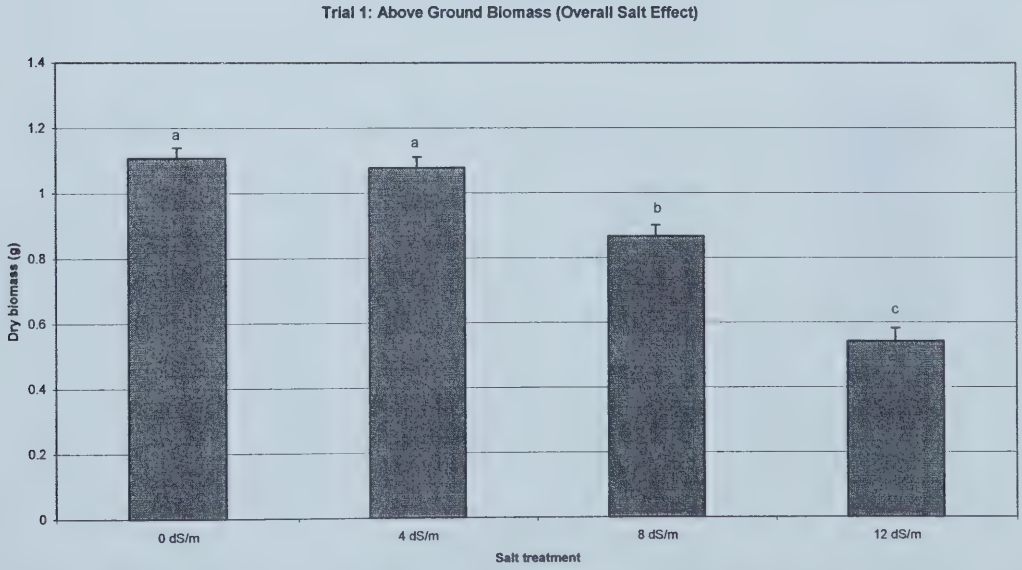

Figure 2.3: Average (LS means) above ground biomass produced per plant at each salt level in trial 1. Bars include all species at all flooding durations. Treatments with common letters are not significantly different (α =0.05).

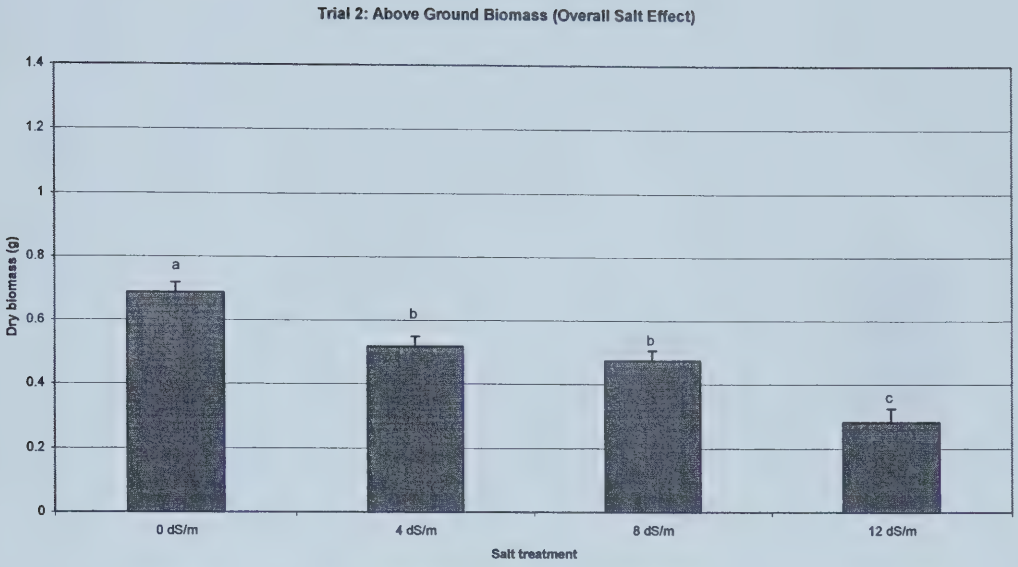

Figure 2.4: Average (LS means) above ground biomass produced per plant at each salt level in trial 2. Bars include all species at all flooding durations. Treatments with common letters are not significantly different (α =0.05).

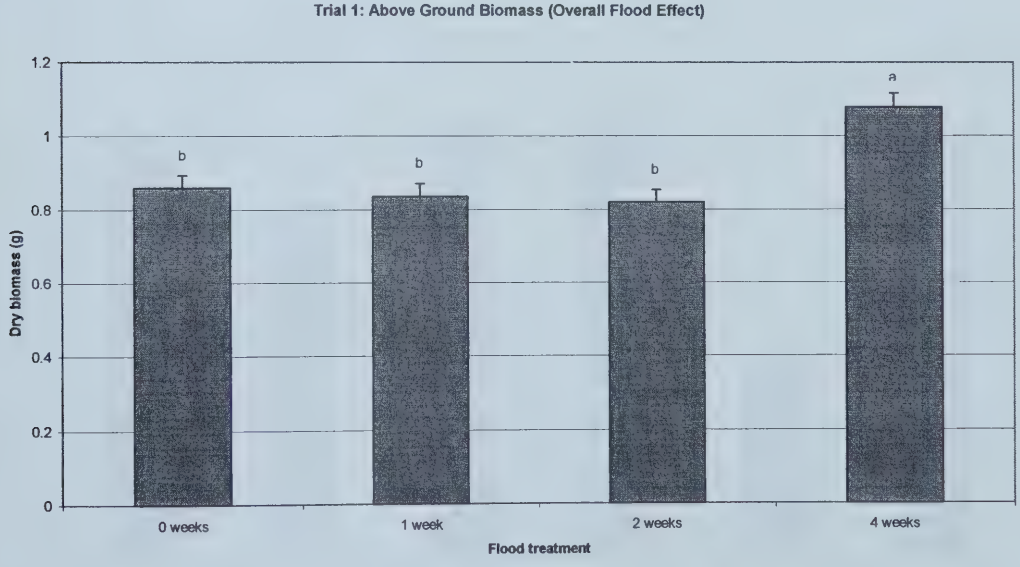

Figure 2.5: Average (LS means) above ground biomass produced per plant at each flooding treatment in trial 1. Bars include all species at all salt levels. Treatments with common letters are not significantly different (α =0.05).

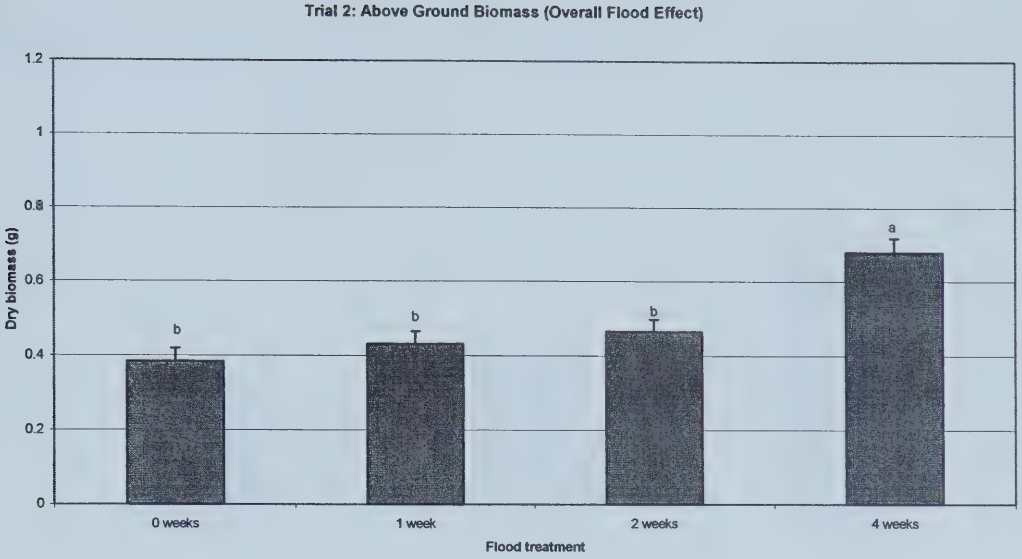

Figure 2.6: Average (LS means) above ground biomass produced per plant at each flooding treatment in trial 2. Bars include all species at all salt levels. Treatments with common letters are not significantly different (α =0.05).

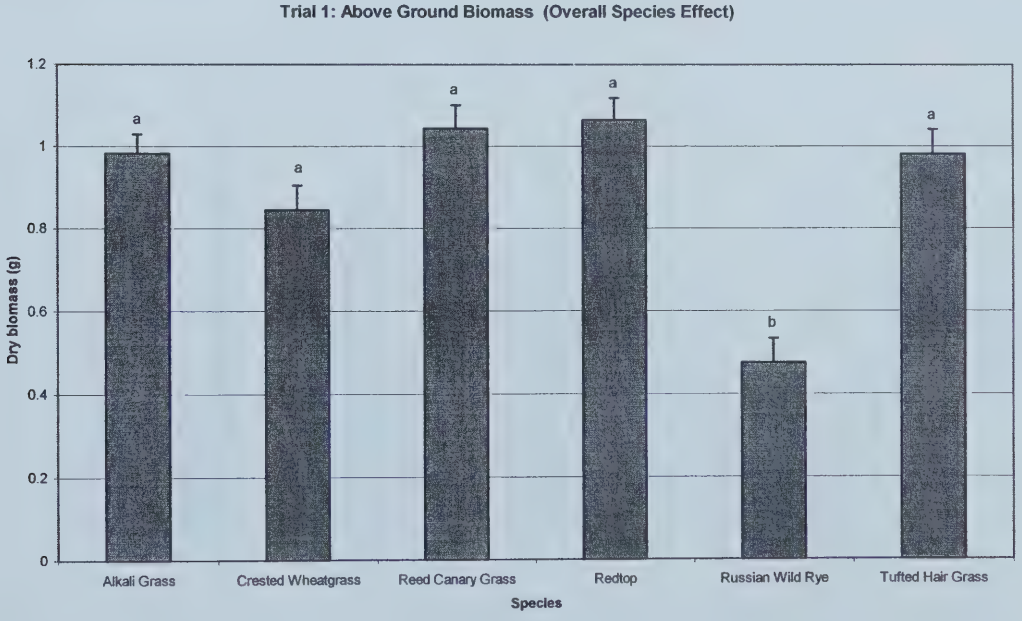

Figure 2.7: Average (LS means) above ground biomass produced per plant by each species in trial 1. Bars include all flooding*salt treatments. Bars with common letters are not significantly different (α =0.05).

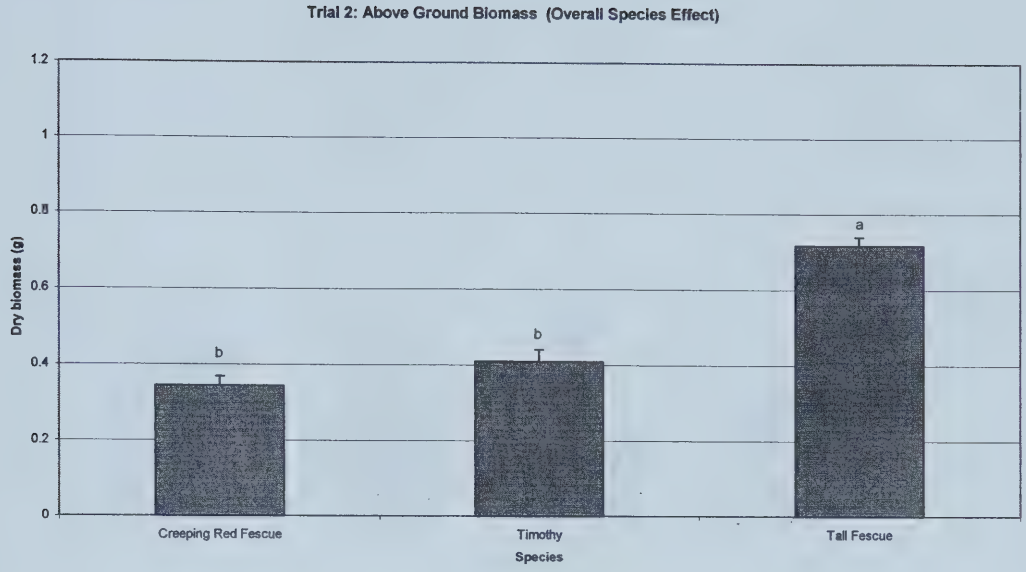

Figure 2.8: Average (LS means) above ground biomass per plant produced by each species in trial 2. Bars include all flood*salt levels. Treatments with common letters are not significantly different (α =0.05).

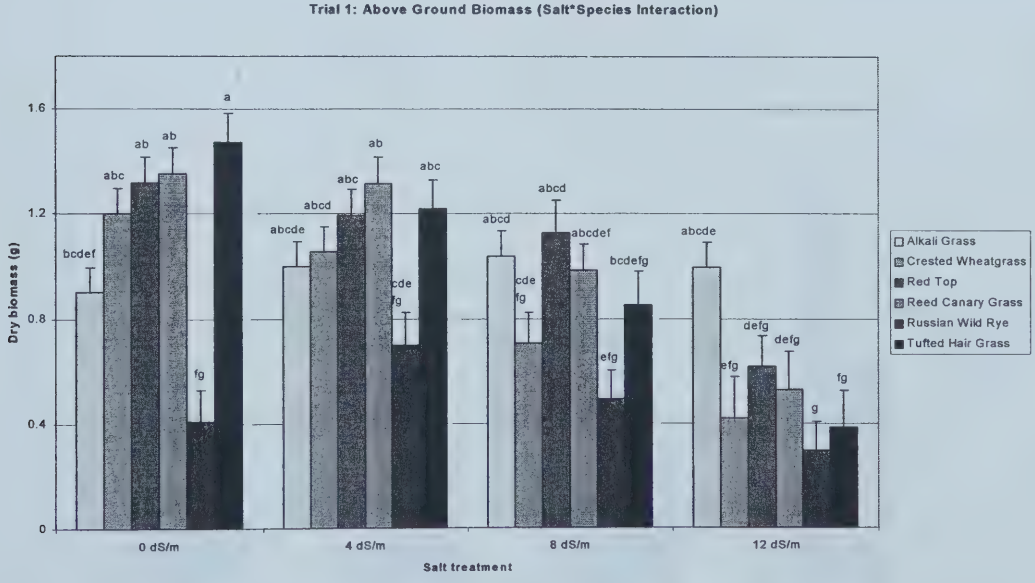

Figure 2.9: Average (LS means) above ground biomass produced per plant by each species at each salt level in trial 1. Bars include all flood treatments. Bars with common letters are not significantly different (α =0.05).

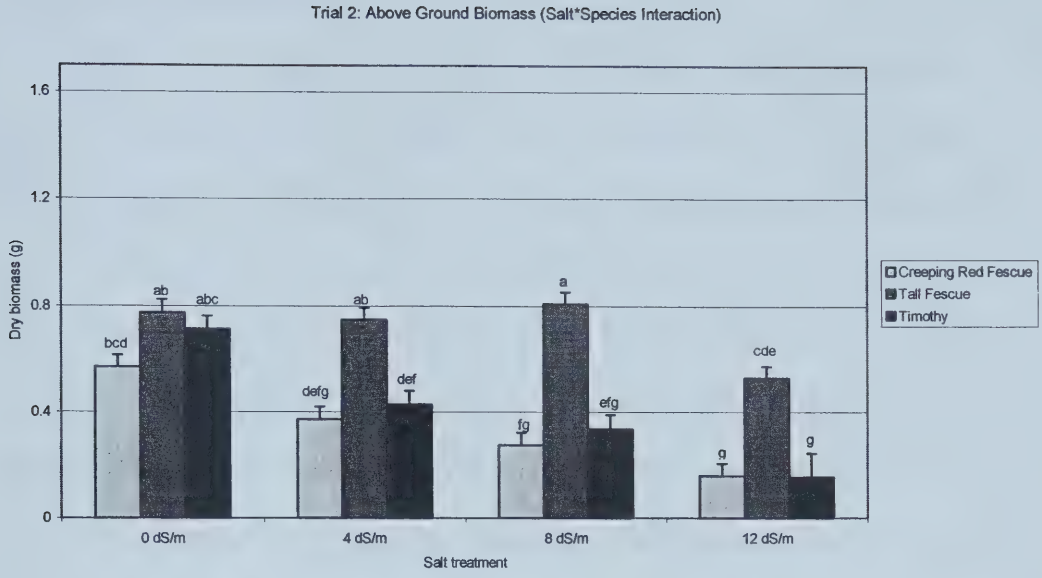

Figure 2.10: Average (LS means) above ground biomass produced per plant by each species at each salt level in trial 2. Bars include all flood treatments. Treatments with common letters are not significantly different (α =0.05).

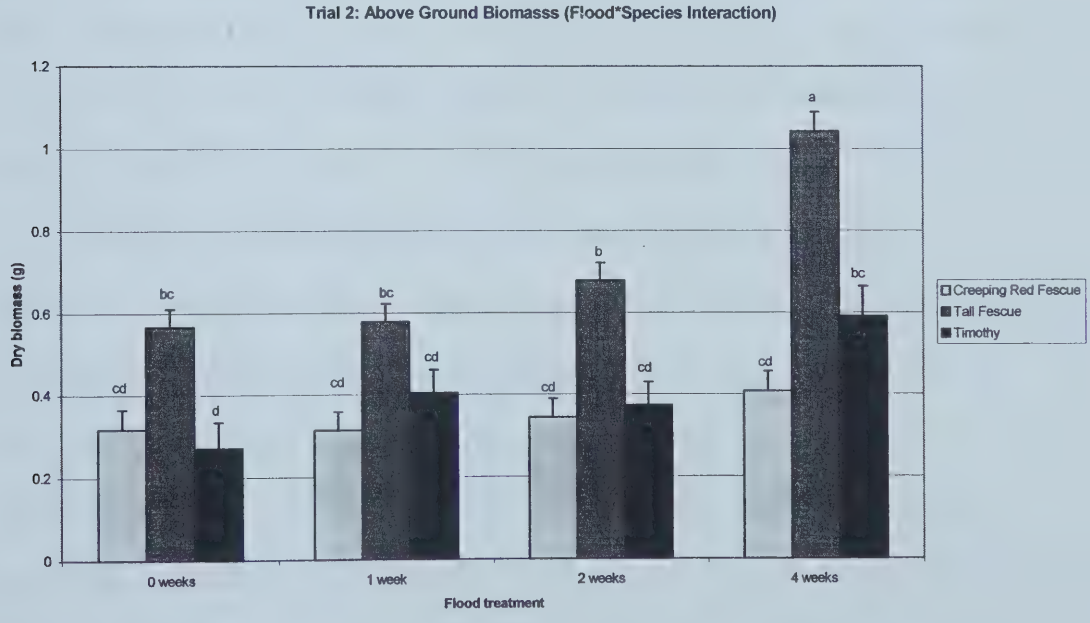

Figure 2.11: Average (LS means) above ground biomass produced per plant by each species at each flood treatment in trial 2. Bars include all salt levels. Treatments with common letters are not significantly different (α =0.05).

2.3.2.3 Below Ground Biomass

In both trials, as expected, the overall salt effect is one where increasing salt levels decreased the overall below ground biomass produced (Figure 2.12). In trial 1, there was no significant difference in the total amount of below ground biomass produced between salt treatment 1 (0 dS/m) and salt treatment 2 (4 dS/m), but both salt treatment 3 and 4 (8 dS/m and 12 dS/m) experienced significant decreases in below ground biomass production when compared to salt treatment 1 and 2. Salt treatment 4 produced significantly less below ground biomass than did salt treatment 3. In trial 2, each increase in salt treatment lead to a significant decrease in the overall amount of below ground biomass produced (Figure 2.13)

In trial 1, the overall flood effect, as expected, is one where increasing flooding durations decreased the overall below ground biomass produced (Figure 2.14). There was a significant decrease in below ground biomass produced from 0 weeks to 1 week of flooding, and from 1 week to 2 weeks of flooding. The decrease in below ground biomass produced from 2 weeks to 4 weeks was not significant.

In trial 1, the overall species effect showed that both Redtop and Crested Wheatgrass produced significantly more below ground biomass than all the other species (Figure 2.15). Reed Canary Grass produced significantly more below ground biomass than both Alkali Grass and Tufted Hair Grass, which produced significantly more biomass than Russian Wild Rye. Russian Wild Rye produced significantly less below ground biomass when compared to all other species. In trial 2, the overall species effect showed that Tall Fescue produced significantly more below ground biomass than both

Timothy and Creeping Red Fescue (Figure 2.16). Timothy produced significantly more below ground biomass than Creeping Red Fescue.

When comparing the salt effect on each of the different species in trial 1, (the salt*species interaction), it was interesting to note again that while all other species experienced significant decreases in below ground biomass production with increasing salt levels (from the 0 dS/m treatment level to the 12 dS/m level), both Alkali Grass and Russian Wild Rye did not show a significant decrease (Figure 2.17). Russian Wild Rye showed a significant increase in the amount of root biomass produced from the 0 dS/m treatment to the 4 dS/m treatment, suggesting a slight stimulatory effect at this salt level. Crested Wheatgrass produced significantly more below ground biomass at the 0 and 4 dS/m treatment levels than all other species. Alkali Grass produced significantly more than both Russian Wild Rye and Tufted Hair Grass at the 12 dS/m treatment level. Reed Canary Grass produced significantly more root biomass than Tufted Hair Grass at the 12 dS/m level; the differences between all other species at the 12 dS/m level were not significantly different. In trial 2, when comparing the salt effect on each of the different species, all species showed a significant decrease in root production from 0 dS/m to 4 dS/m and from both of these to 12 dS/m (Figure 2.18). Creeping Red Fescue and Tall Fescue also showed significant decreases in root production from 8 dS/m to 12 dS/m. Under all salt treatments, Tall Fescue produced significantly more below ground biomass than both Timothy and Creeping Red Fescue. At the 0 dS/m treatment level, Timothy produced significantly more biomass than did Creeping Red Fescue, but there was no significant difference in root production between the two at any other salt level.

Comparison of the effect of increasing flooding durations on each of the different species in trial 1 (the flood*species interaction), showed that both Alkali Grass and Redtop exhibited a significant decrease in the amount of below ground biomass produced from no flooding to 4 weeks of flooding (Figure 2.19). Alkali Grass experienced a decrease from 2 weeks to four weeks (with no significant difference between 0, 1 and 2 weeks), Redtop experienced a decrease from 0 weeks to 1 week (with no further significant differences between 1, 2 and 4 weeks, which suggested an adaptation throughout the 4 weeks of flooding). Crested Wheatgrass and Russian Wild Rye actually experienced an increase in amount of root biomass produced at the 1 week of flooding (not significantly greater than with no flooding, but is significantly greater than at 2 and 4 weeks of flooding). Tufted Hair Grass did not experience any significant increase or decrease in the amount of below ground biomass produced over any of the treatments. Reed Canary Grass experienced a significant increase in below ground biomass after 4 weeks of flooding when compared to 1 and 2 weeks (but was not significantly different from the 0 weeks treatment). In trial 2, when comparing the effect of increasing flooding durations on each of the different species, there was no significant difference in Creeping Red Fescue over all flood treatments (Figure 2.20). Tall Fescue actually produced significantly less root biomass without any flooding than it did for 1 to 4 weeks of flooding. Tall Fescue produced significantly more below ground biomass than both Creeping Red Fescue and Timothy at all flood levels. Timothy produced significantly more root biomass than did Creeping Red Fescue at one week of flooding, but at no other treatment level. Timothy produced significantly less biomass at 0 weeks of flooding than at 1 week or 4 weeks.

The salt*flood*species interaction was significant for the amount of below ground biomass produced in both trial 1 and 2, which means that the amount of root biomass produced for at least one species was significantly affected by the interaction of both salt and flooding together. This is a very complicated relationship to illustrate and interpret, so the results are presented in the Appendix in Table A-1 for trial 1 and Table A-2 for trial 2 rather than in graphs.

Table 2.14: Analysis of Variance for trial 1 for below ground biomass data Type III SS.

Sources of Variation	D.F.	F Value	Pr>F
Block	2	3.20	0.0552
Salt	3	33.87	<0.0001
Flood	3	4.84	0.0073
Error = Block*Salt*Flood	30	5.14	<0.0001
Species	5	65.19	<0.0001
Salt*Species	15	26.30	<0.0001
Flood*Species	15	8.77	<0.0001
Salt*Flood*Species	45	4.40	<0.0001

Table 2.15: Analysis of Variance for trial 2 for below ground biomass data Type III SS.

Sources of Variation	D.F.	F Value	Pr>F
Block	2	3.55	0.0412
Salt	3	32.23	<0.0001
Flood	3	1.70	0.1877
Error = Block*Salt*Flood	30	11.06	<0.0001
Species	2	608.24	<0.0001
Salt*Species	6	13.56	<0.0001
Flood*Species	6	7.42	<0.0001
Salt*Flood*Species	18	3.78	<0.0001

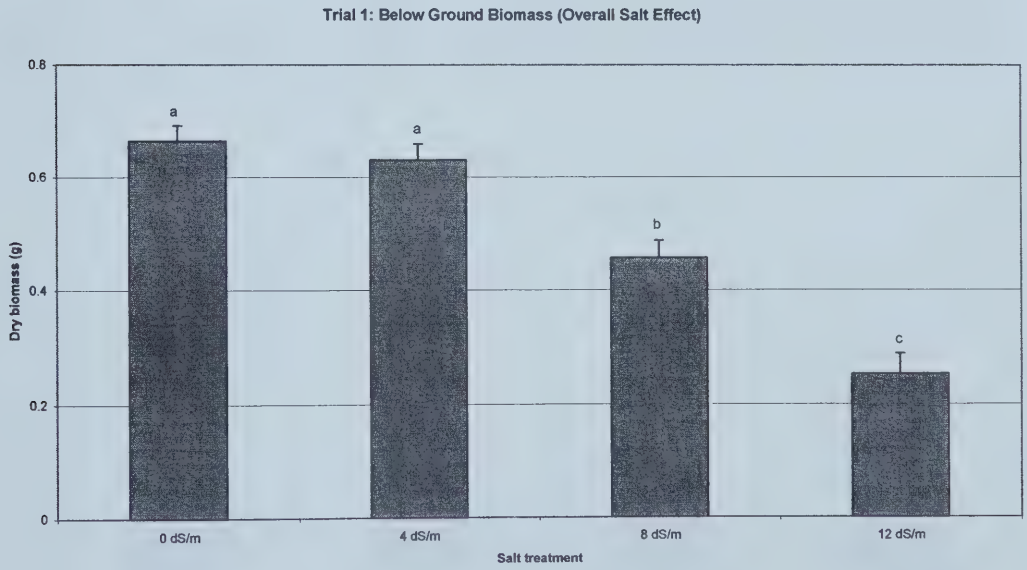

Figure 2.12: Average amount (LS means) of average below ground biomass produced at each salt level (total amount below ground biomass per pot/number of survived plants per pot) in trial 1. Bars include all species at all flooding durations. Treatments with common letters are not significantly different (α =0.05).

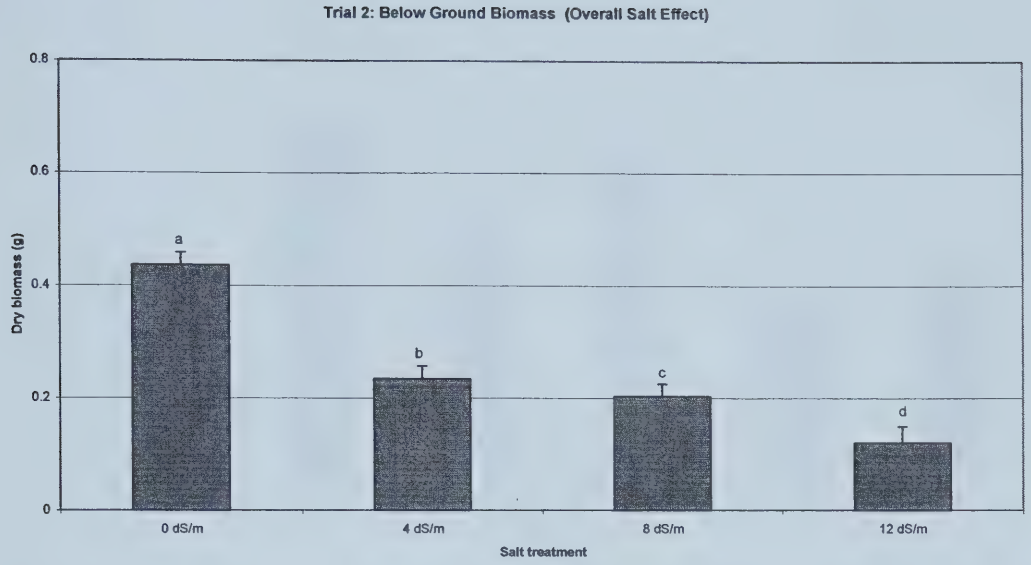

Figure 2.13: Average amount (LS means) of average below ground biomass produced at each salt level (total below ground biomass per pot/number of survived plants per pot) in trial 2. Bars include all species at all flood treatments. Treatments with common letters are not significantly different (α =0.05).

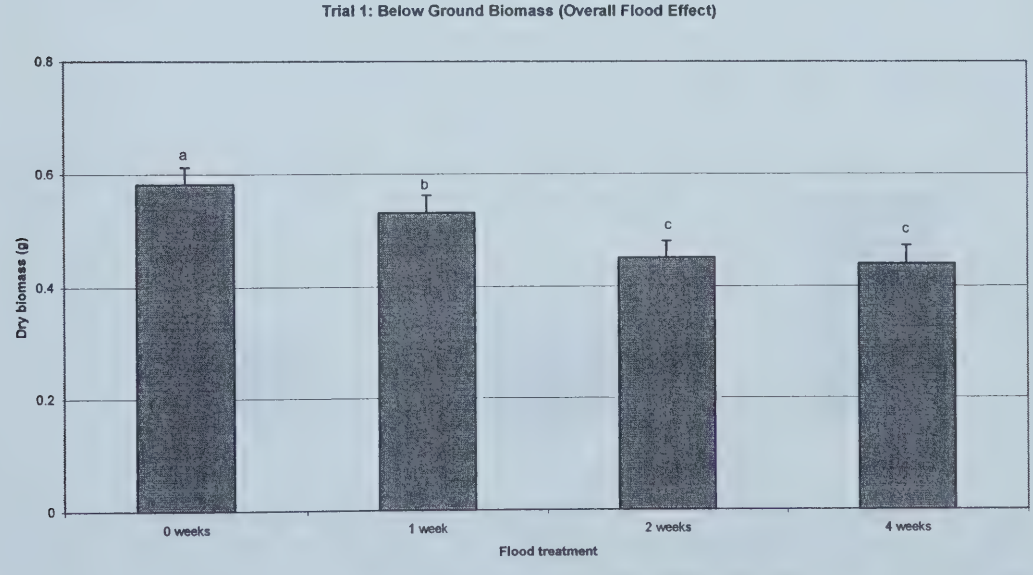

Figure 2.14: Average amount (LS means) of average below ground biomass produced at each flood level (total amount below ground biomass per pot/number of survived plants per pot) in trial 1. Bars include all species at all salt treatments. Treatments with common letters are not significantly different (α =0.05).

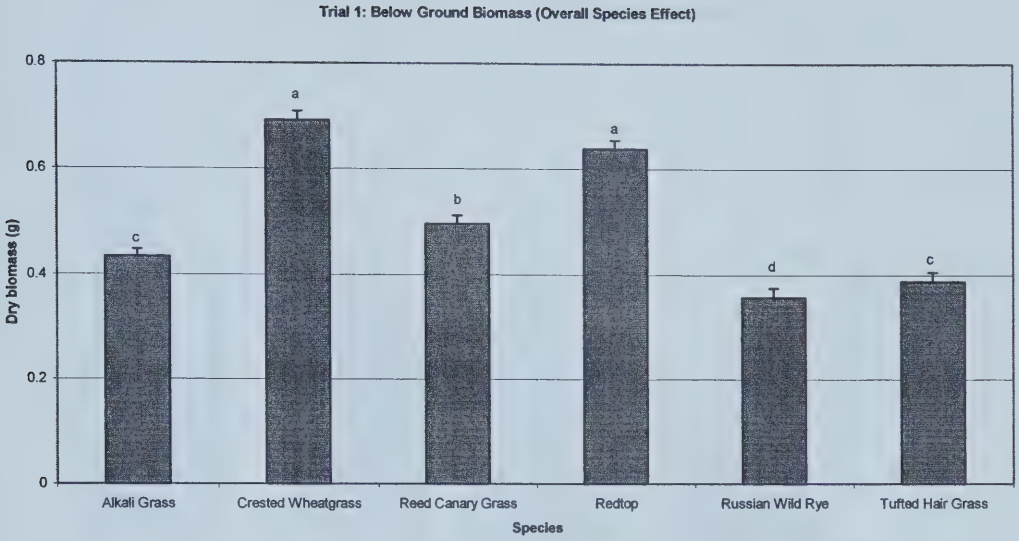

Figure 2.15: Average amount (LS means) of average below ground biomass produced by each species (total amount below ground biomass per pot/number of survived plants per pot) in trial 1. Bars include all flood*salt treatments. Treatments with common letters are not significantly different (α =0.05).

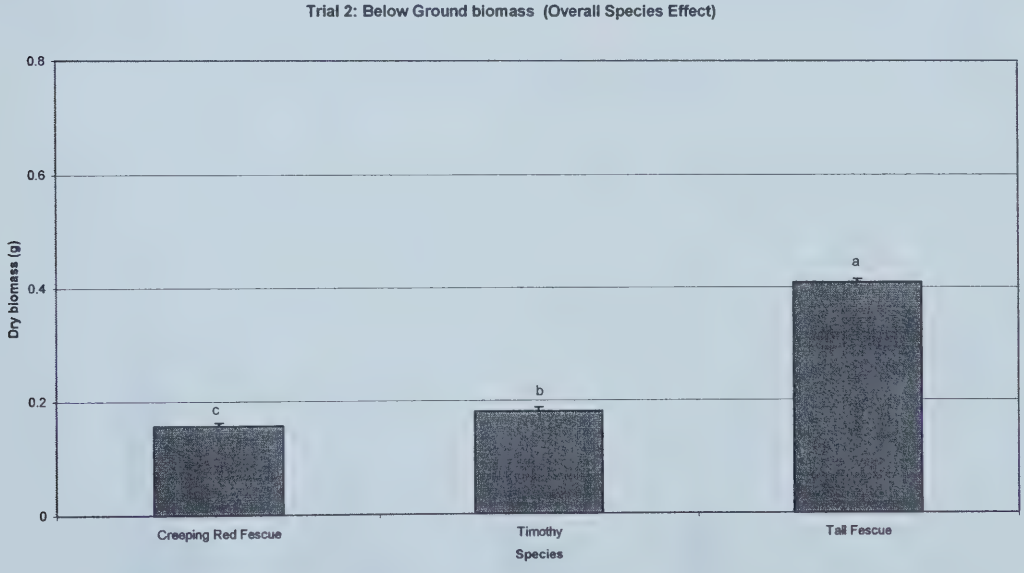

Figure 2.16: Average amount (LS means) of average below ground biomass produced by each species (total below ground biomass per pot/number of survived plants per pot) in trial 2. Bars include all flood*salt treatments. Treatments with common letters are not significantly different (α =0.05).

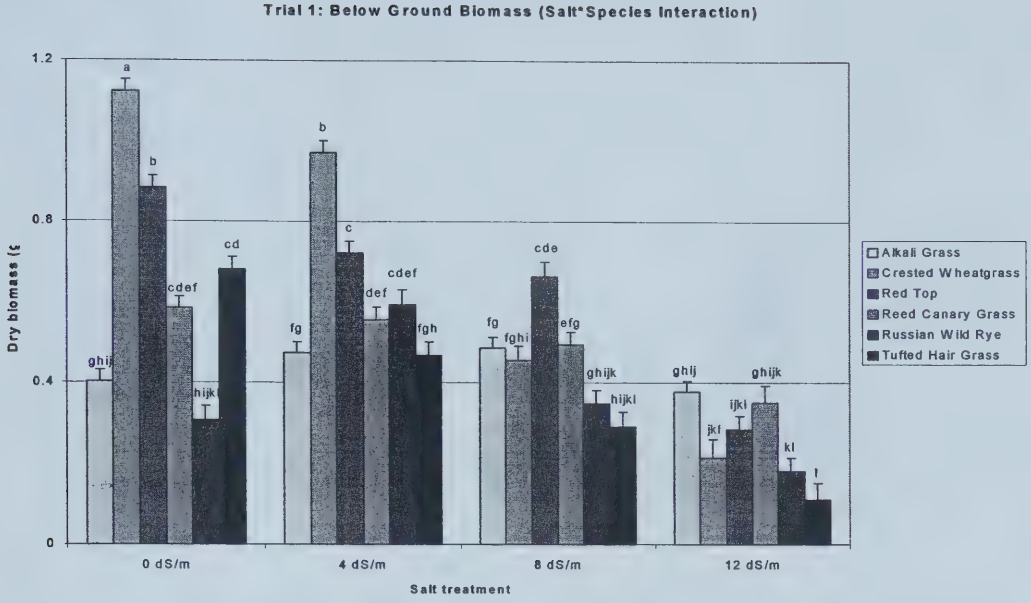

Figure 2.17: Average amount (LS means) of average below ground biomass produced by each species at each salt level (total amount below ground biomass per pot/number of survived plants per pot) in trial 1. Bars include all flood treatments. Bars with common letters are not significantly different (α =0.05).

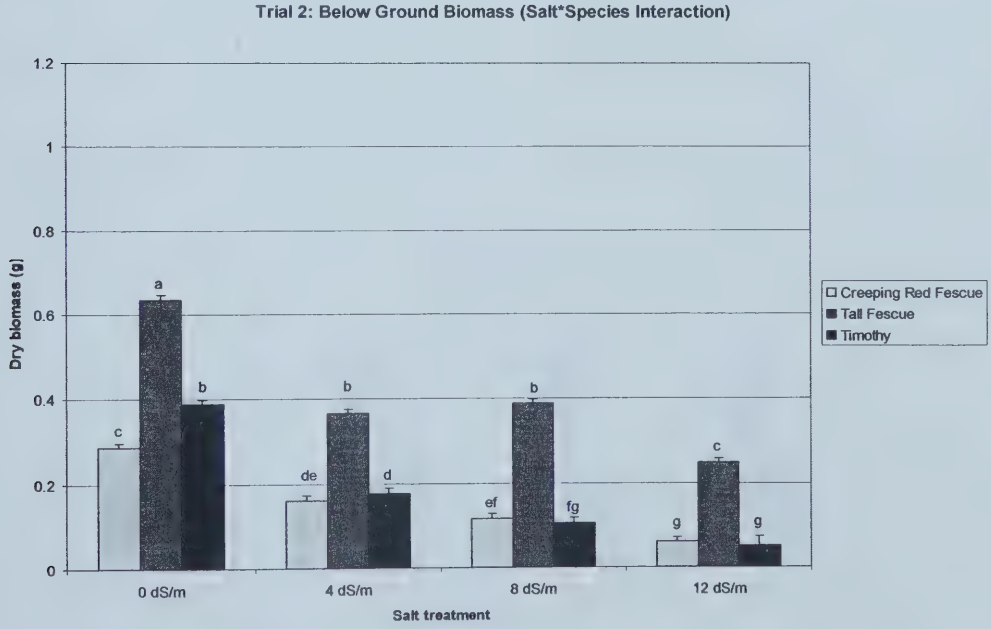

Figure 2.18: Average amount (LS means) of average below ground biomass produced by each species at each salt level (total below ground biomass per pot/number of survived plants per pot) in trial 2. Bars include all flood treatments. Treatments with common letters are not significantly different (α =0.05).

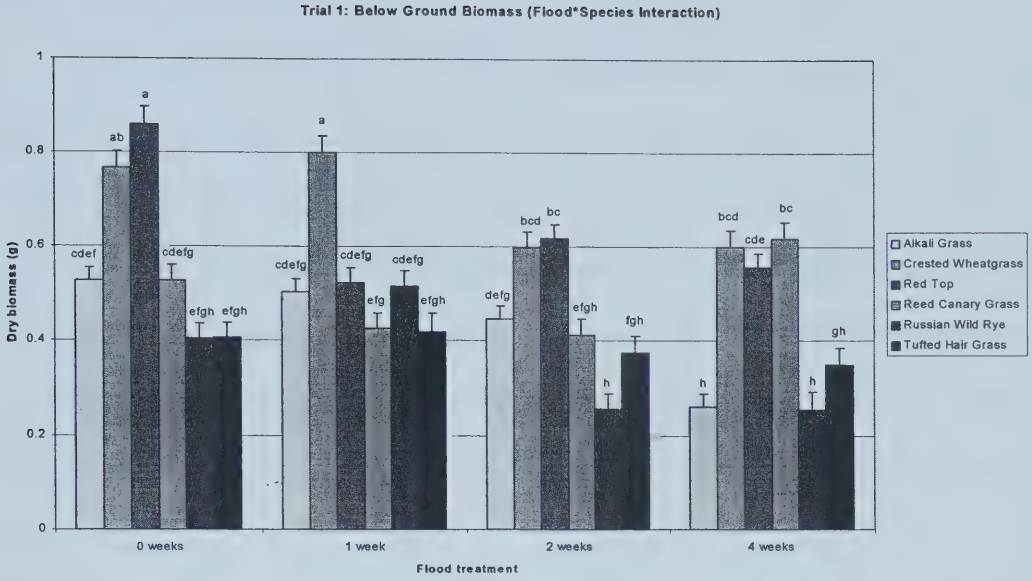

Figure 2.19: Average amount (LS means) of average below ground biomass produced by each species at each flood treatment (total amount below ground biomass per pot/number of survived plants per pot) in trial 1. Bars include all salt treatments. Bars with common letters are not significantly different (α =0.05).

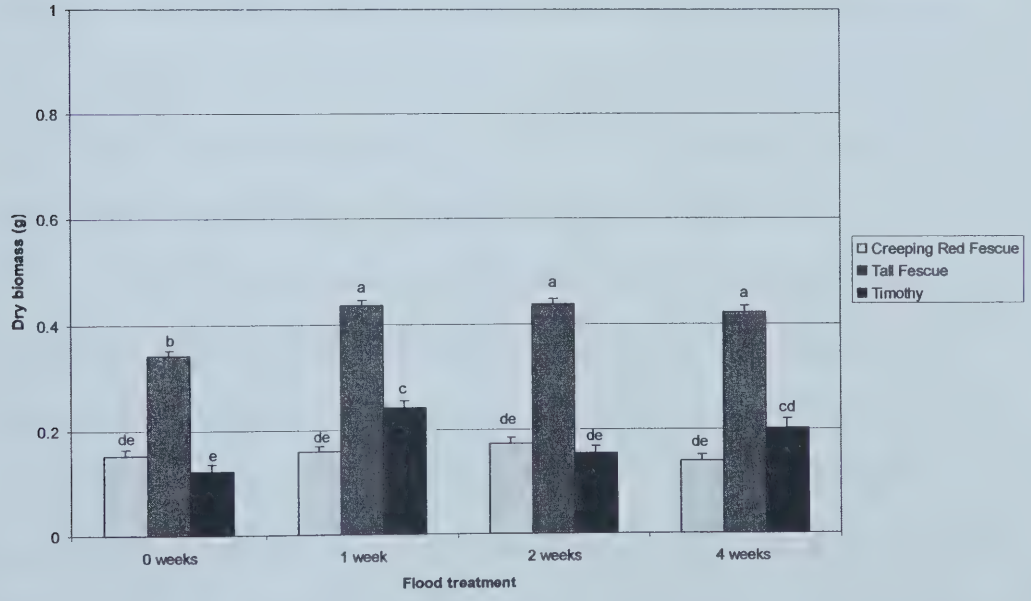

Figure 2.20: Average amount (LS means) of average below ground biomass produced by each species at each flood treatment (total below ground biomass per pot/number of survived plants per pot) in trial 2. Bars include all salt levels. Treatments with common letters are not significantly different (α =0.05).

2.3.2.4 Root to Shoot Ratio

In both trials, the overall salt effect is one where increasing salt levels decreased the overall root to shoot ratio (Figures 2.21 and 2.22). In trial 1, the root to shoot ratio produced under the 0 dS/m salt level was significantly greater than that produced at 12 dS/m. There were no significant differences between any of the other treatments. In trial 2, the root to shoot ratio produced at the 0 dS/m salt level was significantly greater than that of all other treatments. Salt level 2 (4 dS/m) had a significantly greater root to shoot ratio than did salt level 4 (12 dS/m). There were no differences between any of the other treatments.

In trial 1, the overall flood effect is one where increasing flooding durations decreased the overall root to shoot ratio (Figure 2.23). In trial 1, the root to shoot ratio produced without flooding was significantly greater than that produced at 4 weeks of flooding. There were no significant differences between any of the other treatments. In trial 2, the root to shoot ratios produced at the 0, 1 and 2 weeks of flooding were significantly greater than was produced under 4 weeks of flooding (Figure 2.24). There were no significant differences between any of the other treatments.

In trial 1, the overall species effect showed that Alkali Grass produced a significantly lower root to shoot ratio than all the other species except Tufted Hair Grass (Figure 2.25). Tufted Hair Grass produced significantly lower root to shoot ratios than Crested Wheatgrass and Russian Wild Rye. There were no significant differences between the other species. In trial 2, the overall species effect showed that Tall Fescue produced significantly greater root to shoot ratios than Timothy (Figure 2.26). No differences existed between the other species.

Table 2.16: Analysis of Variance for trial 1 for root:shoot data Type III SS.

Sources of Variation	D.F.	F Value	Pr>F
Block	2	0.48	0.6207
Salt	3	3.86	0.0189
Flood	3	5.29	0.0048
Error = Block*Salt*Flood	30	1.02	0.4375
Species	5	8.39	<0.0001
Salt*Species	15	1.25	0.2315
Flood*Species	15	0.35	0.9896
Salt*Flood*Species	45	0.77	0.8599

Table 2.17: Analysis of Variance for trial 2 for root:shoot data Type III SS.

Sources of Variation	D.F.	F Value	Pr>F
Block	2	5.47	0.0094
Salt	3	16.76	<0.0001
Flood	3	5.98	0.0025
Error = Block*Salt*Flood	30	0.76	0.8144
Species	2	4.98	0.0073
Salt*Species	6	1.10	0.3609
Flood*Species	6	0.98	0.4353
Salt*Flood*Species	18	0.63	0.8764

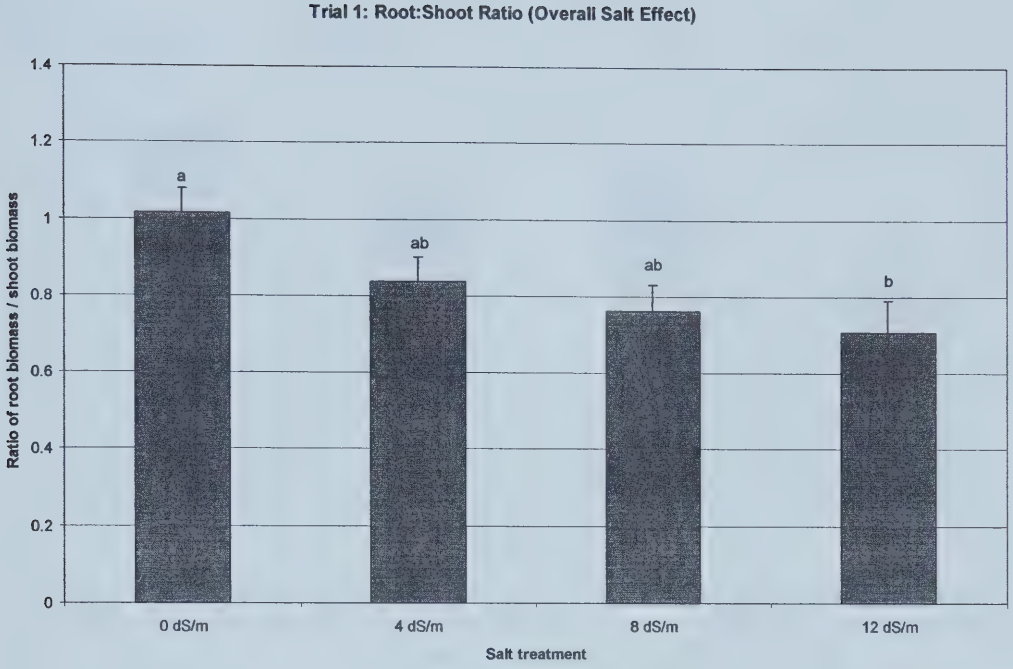

Figure 2.21: Average (LS means) overall root to shoot ratio for each salt treatment (shoot biomass/average root biomass for each treatment) in trial 1. Bars include all species at all flood levels. Treatments with common letters are not significantly different (α =0.05).

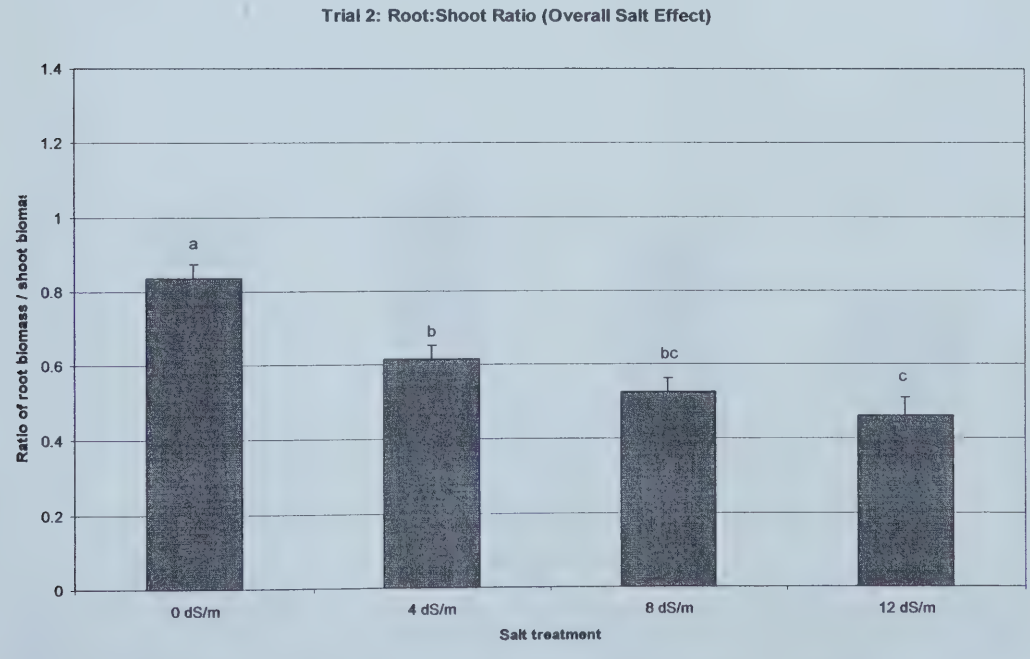

Figure 2.22: Average (LS means) overall root to shoot ratio for each salt treatment (shoot biomass/average root biomass for each treatment) in trial 2. Bars include all species at all flood levels. Treatments with common letters are not significantly different (α =0.05).

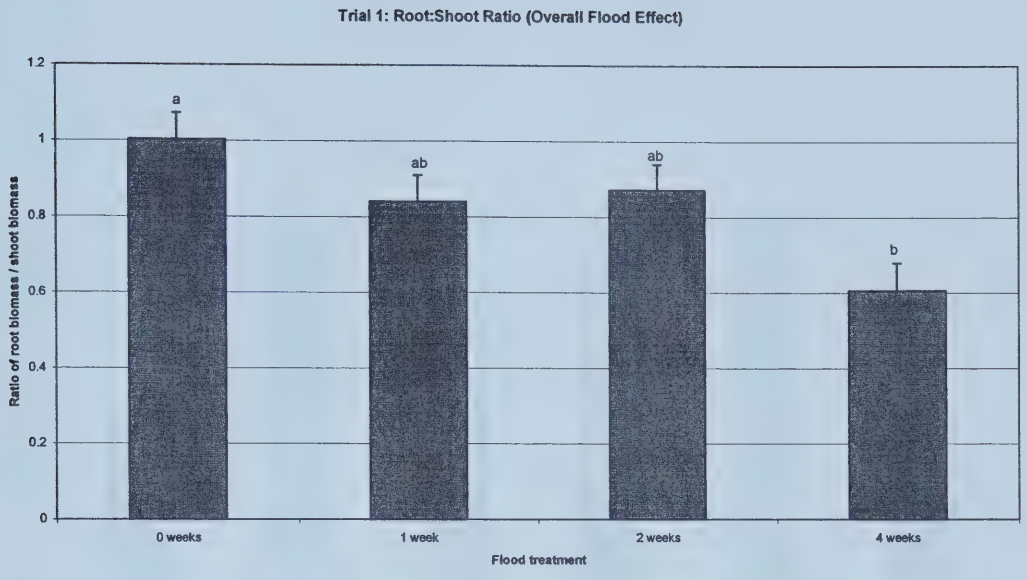

Figure 2.23: Average (LS means) overall root to shoot ratio for each flood treatment (shoot biomass/average root biomass for each treatment) in trial 1. Bars include all species at all flood levels. Treatments with common letters are not significantly different (α =0.05).

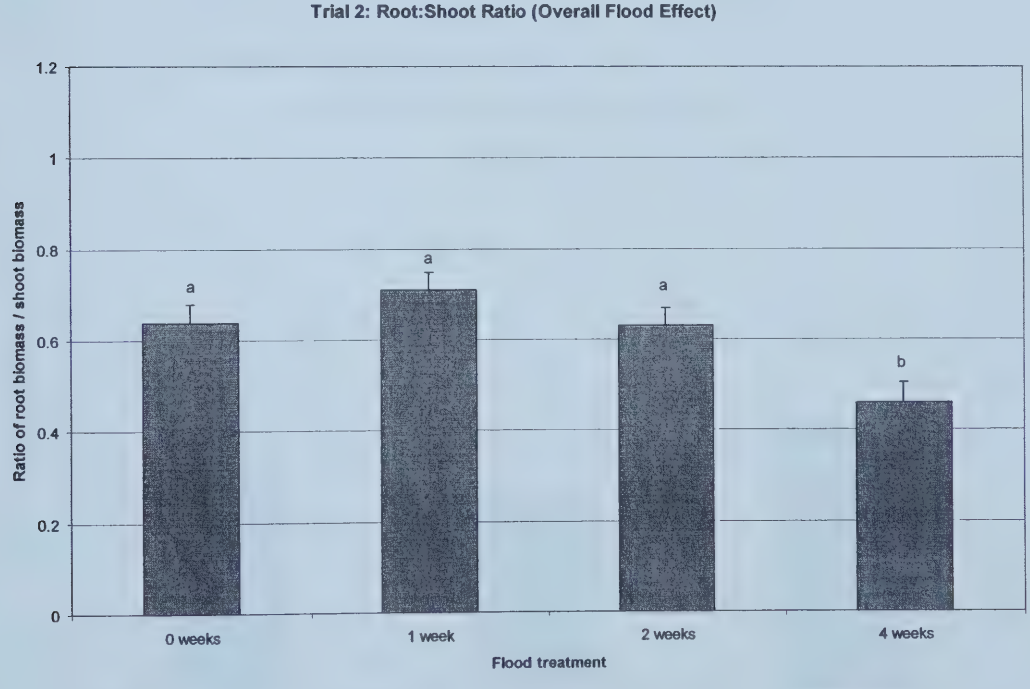

Figure 2.24: Average (LS means) overall root to shoot ratio for each flood treatment (shoot biomass/average root biomass for each treatment) in trial 2. Bars include all species at all flood levels. Treatments with common letters are not significantly different (α =0.05).

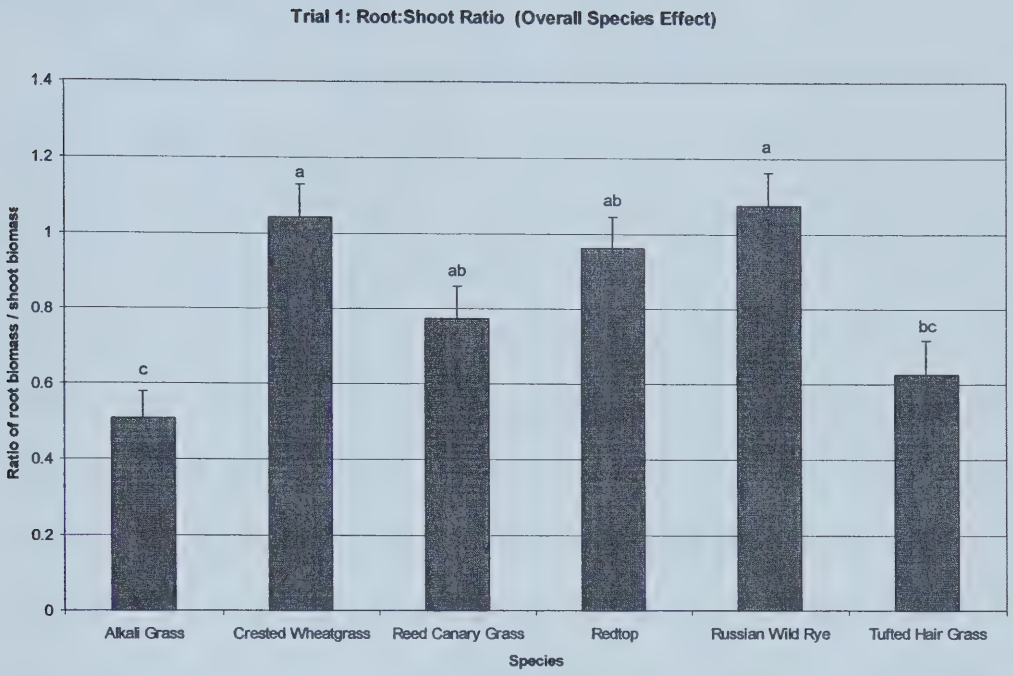

Figure 2.25: Average (LS means) overall root to shoot ratio for each species (shoot biomass/average root biomass for each treatment) in trial 1. Bars include all salt*flood levels. Treatments with common letters are not significantly different (α =0.05).

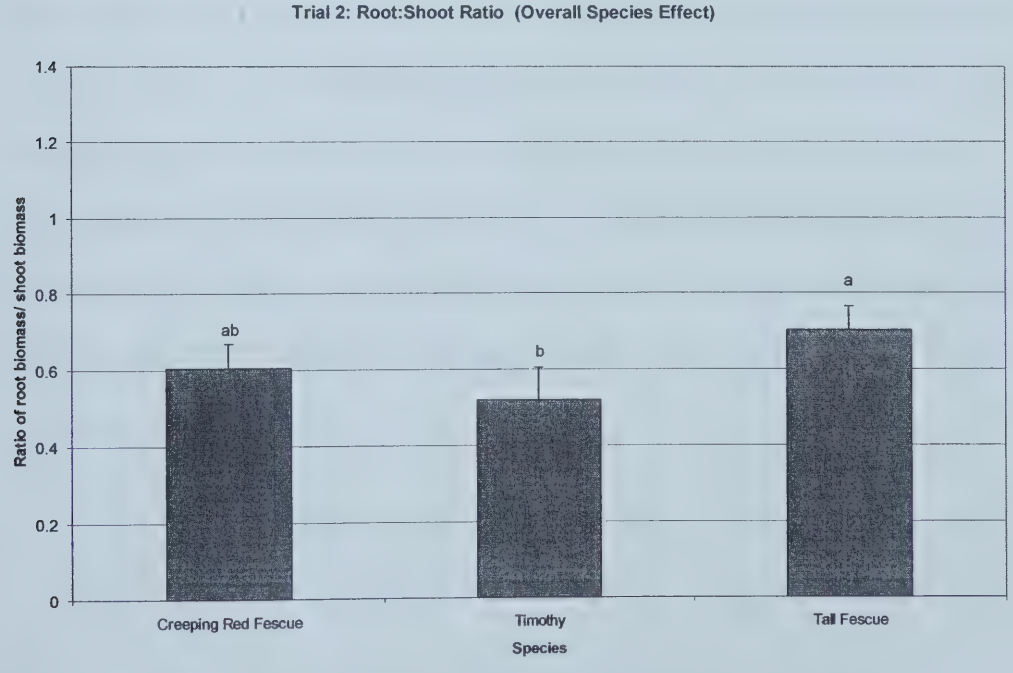

Figure 2.26: Average (LS means) overall root to shoot ratio for each species (shoot biomass/average root biomass for each treatment) in trial 2. Bars include all salt*flood levels. Treatments with common letters are not significantly different (α =0.05).

2.3.2.5 Forage Quality Analysis

The forage analysis was completed in order to determine if any of the species used in this experiment were sub-standard in terms of quality for animal feed. Due to the harvest early in the growth cycle (before maturity), all of the species had very good crude protein content, high percentages of total digestible nutrients (Church, 1977), and normal to high essential mineral contents (McDonald et al., 1988). According to McDonald et al. (1988), the stage of growth is the most important factor influencing the nutritive value of forage. In general, recommended crude protein content (%) ranges from 9 for a lactating cow to 15 for a weaning calf, and recommended total digestible nutrients (%) ranges from 52 for a lactating cow to 74 for a calf to be fattened (Church, 1977). For comparison purposes, normal ranges of essential mineral content for pasture grasses are presented in Table A-3 in the appendix. Because the samples were not large enough, all sub-samples and replicates of each treatment were combined; thus, statistical analysis was not possible. However, there were a few trends that were interesting to note. For example, the crude protein content of all of the species except Crested Wheatgrass was highest with the longest duration of flooding when averaging across all salt treatments (Figure 2.27). Unsurprisingly, both the sodium content (Na) and magnesium content (Mg) increased with increased levels of salt for the majority of species, when averaging across all levels of flooding (Tables 2.18 (a-i)).

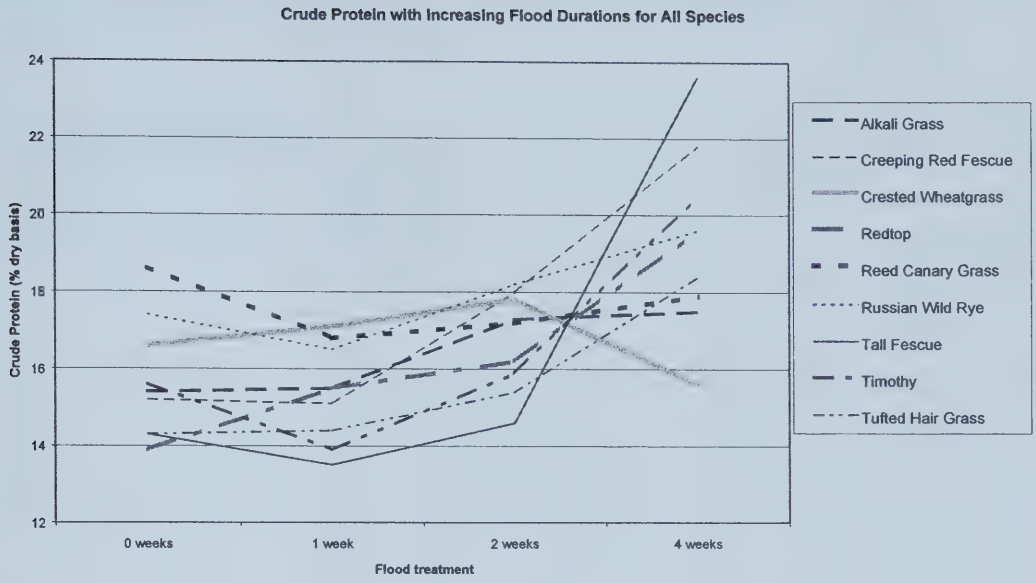

Figure 2.27: Crude protein (% dry basis) for all species (trials 1 and 2) with increasing durations of flooding.

Tables 2.18 (a-i): Forage quality analysis for each species*salt*flooding treatment for all species.

Table 2.18 (a): Alkali Grass

Treatment			Feed Analysis (on dry basis)*				Minerals (% on dry basis)				
Species	Salt (dS/m)	Flood (weeks)	CP %	ADF %	TDN %	DE (MCal/kg)	Ca	P	K	Mg	Na
AG	0	0	16.0	33.2	64.83	2.85	0.60	0.41	2.88	0.31	0.08
		1	15.8	33.3	64.67	2.85	0.56	0.37	2.61	0.29	0.11
		2	17.2	31.4	67.58	2.97	0.60	0.41	3.53	0.30	0.08
		4	17.5	30.5	68.89	3.03	0.73	0.38	3.28	0.33	0.14
AG	4	0	14.9	29.8	70.01	3.08	0.41	0.35	2.47	0.56	0.39
		1	14.3	32.1	66.46	2.92	0.45	0.35	2.35	0.66	0.48
		2	17.2	30.5	68.96	3.03	0.46	0.37	2.64	0.64	0.51
		4	13.4	31.5	67.35	2.96	0.32	0.30	2.97	0.59	0.17
AG	8	0	14.7	30.0	69.66	3.07	0.40	0.35	2.20	0.66	0.59
		1	15.2	30.1	69.53	3.06	0.34	0.36	2.26	0.80	0.75
		2	16.6	16.6	71.74	3.16	0.33	0.37	2.53	0.77	0.84
		4	19.4	19.4	76.48	3.37	0.36	0.45	2.49	1.05	1.11
AG	12	0	16.0	28.1	72.55	3.19	0.33	0.37	2.10	0.65	0.75
		1	16.5	29.7	70.15	3.09	0.28	0.34	1.92	0.73	0.86
		2	18.0	30.3	69.18	3.04	0.28	0.39	2.17	0.68	0.89
		4	19.7	28.8	71.43	3.14	0.49	0.45	2.94	0.83	0.79

Table 2.18 (b): Creeping Red Fescue

Treatment			Feed Analysis (on dry basis)*				Minerals (% on dry basis)				
Species	Salt (dS/m)	Flood (weeks)	CP %	ADF %	TDN %	DE (MCal/kg)	Ca	P	K	Mg	Na
CRF	0	0	16.2	33.1	64.99	2.86	0.70	0.45	4.08	0.28	0.06
		1	13.4	30.3	69.20	3.04	0.64	0.39	3.86	0.28	0.05
		2	15.5	31.1	67.99	2.99	0.77	0.36	3.65	0.27	0.05
		4	22.3	29.1	71.05	3.13	0.97	0.46	4.40	0.38	0.08
CRF	4	0	12.3	30.7	68.68	3.02	0.32	0.31	2.95	0.67	0.32
		1	14.1	28.1	72.49	3.19	0.47	0.35	3.10	0.86	0.45
		2	17.7	27.9	72.76	3.20	0.41	0.36	3.78	0.85	0.44
		4	25.1	25.8	75.91	3.34	0.40	0.45	4.21	0.95	0.60
CRF	8	0	13.7	26.9	74.30	3.27	na**	na	na	na	na
		1	16.7	28.3	72.17	3.18	0.32	0.30	3.00	1.06	0.49
		2	21.2	25.9	75.70	3.33	na	na	na	na	na
		4	20.9	26.5	74.85	3.29	na	na	na	na	na
CRF	12	0	18.5	18.3	87.15	3.83	na	na	na	na	na
		1	16.2	25.5	76.33	3.36	na	na	na	na	na
		2	17.6	22.4	80.95	3.56	na	na	na	na	na
		4	17.7	12.5	95.77	4.21	na	na	na	na	na

*CP denotes crude protein, ADF denotes acid detergent fibre, TDN denotes total digestible nutrients, DE denotes digestible energy.
**na denotes data not available.

Table 2.18 (c): Crested Wheatgrass

Treatment			Feed Analysis (on dry basis)				Minerals (% on dry basis)				
Species	Salt (dS/m)	Flood (weeks)	CP %	ADF %	TDN %	DE (MCal/kg)	Ca	P	K	Mg	Na
CWG	0	0	13.8	30.7	68.66	3.02	0.62	0.35	3.26	0.23	0.03
		1	14.0	28.7	71.55	3.15	0.70	0.34	3.31	0.27	0.04
		2	15.2	29.5	70.44	3.10	0.27	0.34	2.35	0.81	0.71
		4	11.1	31.2	67.80	2.98	0.72	0.30	2.90	0.26	0.09
CWG	4	0	14.8	32.1	66.46	2.92	0.34	0.35	2.95	0.58	0.17
		1	14.5	29.8	69.95	3.13	0.37	0.36	2.69	0.61	0.18
		2	16.4	29.1	71.03	3.13	0.35	0.38	2.83	0.57	0.21
		4	16.4	30.0	69.69	3.07	0.34	0.37	2.93	0.87	0.62
CWG	8	0	19.4	27.3	73.74	3.24	na	na	na	na	na
		1	19.3	32.4	66.03	2.91	0.22	0.47	3.16	0.65	0.23
		2	19.6	29.6	70.23	3.09	na	na	na	na	na
		4	20.1	26.8	74.45	3.28	0.29	0.41	2.42	1.62	1.23
CWG	12	0	18.5	34.1	63.50	2.79	na	na	na	na	na
		1	20.7	na	na	na	na	na	na	na	na
		2	20.2	na	na	na	na	na	na	na	na
		4	14.8	na	na	na	na	na	na	na	na

Table 2.18 (d): Redtop

Treatment			Feed Analysis (on dry basis)				Minerals (% on dry basis)				
Species	Salt (dS/m)	Flood (weeks)	CP %	ADF %	TDN %	DE (MCal/kg)	Ca	P	K	Mg	Na
RT	0	0	12.9	32.5	65.92	2.90	0.71	0.30	3.19	0.32	0.04
		1	15.4	31.7	67.19	2.96	0.69	0.34	3.39	0.30	0.04
		2	16.7	29.6	70.26	3.09	0.80	0.38	3.68	0.34	0.05
		4	17.6	31.5	67.47	2.97	0.81	0.38	3.61	0.35	0.07
RT	4	0	13.0	31.0	68.22	3.00	0.33	0.30	2.70	0.58	0.13
		1	14.4	31.6	67.27	2.96	0.33	0.30	2.57	0.60	0.17
		2	na	na	na	na	na	na	na	na	na
		4	20.9	27.4	73.46	3.23	0.44	0.46	3.30	1.00	0.56
RT	8	0	13.3	26.0	75.66	3.33	0.28	0.29	2.13	0.72	0.27
		1	15.9	31.8	66.92	2.94	0.24	0.38	2.69	0.81	0.28
		2	15.3	28.1	72.46	3.19	0.27	0.33	2.54	0.91	0.28
		4	19.3	26.2	75.35	3.32	0.22	0.41	2.71	1.24	0.76
RT	12	0	16.2	27.2	73.76	3.25	na	na	na	na	na
		1	16.3	28.4	71.99	3.17	na	na	na	na	na
		2	16.7	24.7	77.57	3.41	na	na	na	na	na
		4	20.5	21.1	82.92	3.65	na	na	na	na	na

*CP denotes crude protein, ADF denotes acid detergent fibre, TDN denotes total digestible nutrients, DE denotes digestible energy.
**na denotes data not available.

Table 2.18 (e): Reed Canary Grass

Treatment			Feed Analysis (on dry basis)				Minerals (% on dry basis)				
Species	Salt (dS/m)	Flood (weeks)	CP %	ADF %	TDN %	DE (MCal/kg)	Ca	P	K	Mg	Na
RCG	0	0	18.1	32.4	66.02	2.90	0.65	0.37	3.62	0.36	0.04
		1	16.1	29.4	70.55	3.10	0.71	0.36	3.51	0.39	0.06
		2	14.5	31.3	67.73	2.98	0.56	0.35	3.26	0.32	0.03
		4	17.7	30.8	68.41	3.01	0.62	0.45	3.66	0.41	0.08
RCG	4	0	14.8	30.4	69.00	3.04	0.29	0.32	2.88	0.69	0.39
		1	13.9	31.3	67.67	2.98	0.39	0.31	2.82	0.73	0.30
		2	15.4	30.6	68.79	3.03	0.33	0.35	2.92	0.61	0.32
		4	16.9	31.3	67.79	2.98	0.30	0.42	3.05	0.95	0.67
RCG	8	0	22.6	22.9	80.32	3.53	0.32	0.46	2.46	1.30	1.56
		1	16.3	28.4	72.11	3.17	0.24	0.35	2.38	0.91	0.66
		2	18.4	26.6	74.77	3.29	0.25	0.46	2.69	1.08	0.81
		4	17.9	30.0	69.63	3.06	0.25	0.52	2.75	1.50	1.38
RCG	12	0	18.9	27.2	73.83	3.25	na	na	na	na	na
		1	21.0	na	na	na	na	na	na	na	na
		2	20.4	na	na	na	na	na	na	na	na
		4	18.9	na	na	na	na	na	na	na	na

Table 2.18 (f): Russian Wild Rye

Treatment			Feed Analysis (on dry basis)				Minerals (% on dry basis)				
Species	Salt (dS/m)	Flood (weeks)	CP %	ADF %	TDN %	DE (MCal/kg)	Ca	P	K	Mg	Na
RWR	0	0	17.9	29.4	70.54	3.10	na	na	na	na	na
		1	19.2	31.4	67.57	2.97	na	na	na	na	na
		2	17.9	na	na	na	na	na	na	na	na
		4	17.2	30.0	69.64	3.06	na	na	na	na	na
RWR	4	0	17.2	32.3	66.28	2.92	0.33	0.44	3.81	0.61	0.23
		1	11.3	29.9	69.83	3.07	0.32	0.28	2.47	0.59	0.17
		2	18.4	33.7	64.11	2.82	na	na	na	na	na
		4	21.8	30.3	69.28	0.87	na	na	na	na	na
RWR	8	0	15.9	29.6	70.22	3.09	na	na	na	na	na
		1	16.6	30.5	68.90	3.03	na	na	na	na	na
		2	17.7	33.1	65.06	2.86	na	na	na	na	na
		4	18.5	28.9	71.26	3.14	na	na	na	na	na
RWR	12	0	18.6	30.3	69.18	3.04	na	na	na	na	na
		1	19.0	na	na	na	na	na	na	na	na
		2	18.6	na	na	na	na	na	na	na	na
		4	20.7	na	na	na	na	na	na	na	na

*CP denotes crude protein, ADF denotes acid detergent fibre, TDN denotes total digestible nutrients, DE denotes digestible energy.

**na denotes data not available

Table 2.18 (g): Tall Fescue

Treatment			Feed Analysis (on dry basis)				Minerals (% on dry basis)				
Species	Salt (dS/m)	Flood (weeks)	CP %	ADF %	TDN %	DE (MCal/kg)	Ca	P	K	Mg	Na
TF	0	0	15.8	29.9	69.84	3.07	0.92	0.30	3.72	0.77	0.05
		1	14.0	30.7	68.65	3.02	0.89	0.32	3.74	0.79	0.08
		2	13.9	30.8	68.41	3.01	1.05	0.31	3.69	0.74	0.08
		4	21.9	27.3	73.67	3.24	0.95	0.39	4.36	0.67	0.09
TF	4	0	13.9	27.2	73.90	3.25	0.41	0.29	3.06	1.08	0.49
		1	13.1	29.2	70.80	3.12	0.48	0.28	3.16	1.34	0.78
		2	15.7	29.2	70.89	3.12	0.49	0.34	3.52	1.31	0.77
		4	21.9	27.6	73.30	3.23	0.41	0.37	4.00	1.17	0.74
TF	8	0	12.2	26.6	74.70	3.29	0.26	0.23	2.45	1.31	0.78
		1	12.8	25.4	76.58	3.37	0.28	0.24	2.62	1.35	0.95
		2	13.8	26.3	75.18	3.31	0.33	0.27	2.74	1.57	1.18
		4	25.0	25.9	75.79	3.33	0.27	0.43	3.15	1.58	1.61
TF	12	0	15.4	27.5	73.43	3.23	0.21	0.27	2.63	1.51	0.91
		1	14.1	26.4	74.98	3.30	0.21	0.25	2.57	1.39	1.01
		2	15.1	25.9	75.76	3.33	0.22	0.30	2.50	1.61	1.36
		4	25.5	25.5	79.99	3.52	0.20	0.40	3.03	1.79	1.77

Table 2.18 (h): Timothy

Treatment			Feed Analysis (on dry basis)				Minerals (% on dry basis)				
Species	Salt (dS/m)	Flood (weeks)	CP %	ADF %	TDN %	DE (MCal/kg)	Ca	P	K	Mg	Na
T	0	0	15.8	32.0	66.72	2.94	na	na	na	na	na
		1	12.2	32.3	66.19	2.91	0.65	0.29	3.45	0.27	0.05
		2	13.7	32.7	65.67	2.89	0.73	0.30	3.50	0.30	0.06
		4	21.2	30.9	68.36	3.01	0.80	0.44	4.31	0.32	0.05
T	4	0	13.7	27.6	73.24	3.22	0.26	0.32	3.12	0.58	0.28
		1	14.1	32.8	65.44	2.88	0.30	0.37	3.45	0.54	0.24
		2	17.7	28.2	72.39	3.19	0.41	0.39	3.35	0.55	0.55
		4	24.4	30.3	69.18	3.04	na	na	na	na	na
T	8	0	15.4	26.3	75.25	3.31	na	na	na	na	na
		1	14.3	29.4	70.54	3.10	0.27	0.22	2.46	0.89	0.54
		2	16.8	29.7	70.07	3.08	na	na	na	na	na
		4	20.1	33.0	65.22	2.87	na	na	na	na	na
T	12	0	17.3	na	na	na	na	na	na	na	na
		1	14.8	na	na	na	na	na	na	na	na
		2	15.3	na	na	na	na	na	na	na	na
		4	16.1	na	na	na	na	na	na	na	na

*CP denotes crude protein, ADF denotes acid detergent fibre, TDN denotes total digestible nutrients, DE denotes digestible energy.

**na denotes data not available

Table 2.18 (i): Tufted Hair Grass

Treatment			Feed Analysis (on dry basis)				Minerals (% on dry basis)				
Species	Salt (dS/m)	Flood (weeks)	CP %	ADF %	TDN %	DE (MCal/kg)	Ca	P	K	Mg	Na
THG	0	0	13.4	32.6	65.78	2.89	na	na	na	na	na
		1	13.5	34.2	63.43	2.79	0.68	0.34	3.43	0.26	0.05
		2	14.8	29.0	71.09	3.13	0.63	0.40	3.21	0.31	0.04
		4	14.2	28.7	71.63	3.15	0.61	0.36	2.76	0.28	0.07
THG	4	0	14.2	30.3	69.17	3.04	0.29	0.34	2.41	0.54	0.14
		1	14.6	29.4	70.54	3.10	0.27	0.37	2.58	0.53	0.11
		2	13.5	28.6	71.81	3.16	0.31	0.35	2.43	0.61	0.21
		4	18.1	28.6	71.75	3.16	0.31	0.42	2.64	0.80	0.58
THG	8	0	14.7	25.9	75.81	3.34	0.19	0.33	1.95	0.70	0.26
		1	16.0	28.1	72.43	3.19	na	na	na	na	na
		2	16.5	27.8	72.99	3.21	0.19	0.37	1.97	0.74	0.27
		4	19.1	25.1	76.98	3.39	0.16	0.34	2.12	1.05	0.81
THG	12	0	14.7	29.7	70.10	3.08	na	na	na	na	na
		1	13.6	28.9	71.31	3.14	0.69	0.34	2.55	0.28	na
		2	16.6	27.1	74.03	3.26	na	na	na	na	na
		4	22.2	na	na	na	na	na	na	na	na

*CP denotes crude protein, ADF denotes acid detergent fibre, TDN denotes total digestible nutrients, DE denotes digestible energy.

**na denotes data not available

2.4 Discussion

While it has been reported in the literature that the interaction between salt and waterlogging has an adverse effect on the growth of plants (West and Taylor, 1980; Galloway and Davidson, 1993), as in the experiment by Rogers and West (1993), this experiment did not detect significant interactions between species*salinity*flooding for above ground biomass. However, there was a significant interaction for the below ground biomass. The effects of flooding were not as deleterious as expected; increasing flooded durations actually increased the overall amount of above ground biomass produced when combining all species data together, and did not have a significant effect on survival in either trial. However, the decreased root to shoot ratios with increased durations of flooding as seen in the results section may indicate a preferential partitioning

of carbon away from the root zone due to unfavorable conditions (reduced oxygen concentration) (Glińsky and Stępniewski, 1985).

The stimulation of biomass production with increasing flooding may be explained primarily by the fact that plants subjected to longer flooding durations were also continually exposed to the nutrients in the Hoagland's solution for the duration of the flooding treatment, where as the non-flooded plants were not continually exposed to the nutrients, but were instead watered regularly with the solution. An explanation for the minimal effect of flooding on survival may be that while the pots were submerged in treatment solutions for 0 to 4 weeks, they may not have experienced anaerobic conditions due to the growth medium, and/or because of the treatment solutions, which may not have been completely devoid of oxygen. In this experiment, sand was used as a growth medium, which may have allowed for solution movement through the root zone as well as a rapid recovery after flooding was terminated; the larger pore size associated with coarser textured sand particles (0.05-2.00 mm) may have allowed for more rapid exchange of gases between the growth medium and the atmosphere (Hausenbuiller, 1985). As cited in much of the literature, experiments testing the effect of anaerobic or hypoxic conditions on plant growth are usually done hydroponically, where nitrogen gas is bubbled into solution in order to replace oxygen (Ahmad and Wainwright, 1977; Smit et al., 1990; Galloway and Davidson, 1993; Huang et al. 1994), which was not done in this experiment. In order to further explore the minimal flooding impact found in this experiment, and to determine if it was due to the coarse textured growth medium, in the following chapter (chapter 3) we studied the effect of different soil textures (sand, loam and clay) combined with the effects of increasing salinities and flooding durations.

Salt tolerance was the overriding factor in the success of the different species to the various salt*flooding treatments. In general, the effects of increasing salt concentrations on the species tested in this experiment followed closely with results reported in the literature (Phleger, 1971; Sanderson et al., 1997), where salinity negatively affected survival, above ground and below ground biomass production for all species. Based on the results of this experiment, it is more important that a species be salt tolerant than flood tolerant if it is to be planted in an area prone to saline flooded conditions. While this experiment only tested growth and survival of the plant species for a maximum of 5 months, according to Blum (1985), salt tolerance of seedlings is highly predictive of the response of adult plants to salinity.

Salt tolerance is a complex trait (Hasegawa et al., 2000), as there may be physical factors interacting with biochemical or genetic components that confound attempts to provide an adequate definition (Dalton et al., 2000) and/or understanding of it (Hasegawa et al., 2000). There is no clear consensus as to location (root or shoot) of the mechanisms that affect plant salt tolerance (Serrano and Gaxiola, 1994), but it is known that plants may cope with salinity stress in a variety of ways, including: accumulating, extruding or diluting ions and by selective ion absorption (Howes Keiffer and Ungar, 1997; Sanderson et al., 1997).

It was mentioned earlier that both Bird's-foot Trefoil and Alfalfa had approximately 90% death after the period of induced dormancy. This was likely due to putting the plants into the coldroom soon after the removal of above ground biomass. This precluded the legumes the opportunity to allocate carbohydrate resources below ground, which would have enabled them to survive the period of induced dormancy

(Alberta Agriculture, 1981). The disproportional removal of biomass (all biomass except 5 cm was removed) may have affected the grasses with greater above ground biomass to a greater degree than those with lesser amounts, potentially decreasing the ability of those plants to tolerate the following periods of induced dormancy and flooding. This did not appear to be the case in this trial, as species with greater biomass after the establishment phase continued to do well during the flooding phase.

The objective of this study was to determine the range of salt and flooding tolerance of species tested in order to select optimal planting locations within the often complex and variable wetland-cropland ecotone. Each of the species tested in the biomass production component of this experiment showed some form of salt tolerance, with good germination and at least some biomass production under all salt and flooding treatments. As was expected, some species had better salt and flood tolerance than others (higher survival rates and biomass production). In the following section, each of the species tested were ranked (1-6 for trial 1, and 1-3 for trial 2), according to the overall salt tolerance and flood tolerance.

2.4.1 Overall Ranking

In this experiment, survival rates, above ground and below ground biomass of all species tested were thought to be adequate measures indicating plant tolerance to increasing salt and flooded conditions, as all would be important in ensuring establishment of an adequate permanent vegetated buffer strip within wetland-cropland ecotones.

In general, plant species with increased tolerance to salt and flooding stresses should be able to produce more above ground and below ground biomass; tolerant species should also have higher survival rates than less tolerant species. Consequently, in order to determine the overall "success" of the species tested in this experiment at a given salt or flood level (species*treatment level), the LS means of all *significant* response variables (at $\alpha = 0.05$) were added together for a total value used to rank species performance. The LS means of the response variables were added together so as to include all aspects of tolerance that were significantly affected by the salt and flood treatments, because not all species respond to salt and flooding stresses in a similar manner. For instance, plant species with poor survival rates may fail to establish, and even though it may have very good biomass, would still leave much of the soil bare. Conversely, plants with excellent survival, but poor above ground biomass are not much use as a source of forage. All of the response variables measured (survival and above and below ground biomass) were deemed to be equally important for possible use as vegetated buffer strips within wetland-cropland ecotones. The values at each treatment level were compared between species; species performance was ranked according to the total value at each treatment level, with greater total value meaning higher species rank.

In trial 1, both the species*salt and species*flood interactions were significant. The species*salt interaction was significant for all response variables (survival, above ground biomass production, and below ground biomass production) (Tables 2.8, 2.12 and 2.14). The species*flood interaction was only significant in the below ground biomass production response variables (Tables 2.14 and). The overall rankings for species at all salt and all flooding durations follow in Tables 2.19 and 2.20. While root biomass data

appears to contribute a smaller portion of the total (Tables 2.19-2.22), even after setting all response variables to a maximum value of 1.00 (all variables can contribute equally to the total), there were no changes in overall rankings. Consequently, to maintain simplicity, the rankings were calculated by adding the LS means for each significant response variable together for each species at each salt and flood treatment level.

In trial 2, both the species*salt and species*flood interactions were significant. The species*salt interaction was significant for all response variables (survival, above ground biomass production, and below ground biomass production) (Tables 2.9, 2.13 and 2.15). The species*flood interaction was significant in the above ground biomass production, and below ground biomass production response variables (Tables 2.13 and 2.15). The overall rankings for species at all salt and all flooding durations follow (Tables 2.21 and 2.22). While root biomass data appears to contribute a smaller portion of the total (Tables 2.19-2.22), even after setting all response variables to a maximum value of one (all variables can contribute equally to the total), there were no changes in the overall ranking. Consequently, to maintain simplicity, the rankings were calculated by adding the LS means for each significant response variable together for each species at each salt and flood treatment level.

Table 2.19: Overall ranking at each salt level in trial 1 using the LS means for above ground biomass, below ground biomass, and survival.

Species	Salt Level (dS/m)	LS mean of Significant Response Variable			Total	Rank
		Shoot	Root	Survival		
Alkali Grass	0	0.900	0.401	1.00	**2.301**	**5**
Crested Wheatgrass	0	1.199	1.124	0.98	**3.303**	**1**
Redtop	0	1.317	0.886	0.98	**3.183**	**2**
Reed Canary Grass	0	1.352	0.584	0.92	**2.856**	**4**
Russian Wild Rye	0	0.411	0.307	0.67	**1.388**	**6**
Tufted Hair Grass	0	1.471	0.681	0.81	**2.962**	**3**
Alkali Grass	4	0.996	0.473	1.00	**2.469**	**4**
Crested Wheatgrass	4	1.052	0.973	0.94	**2.965**	**1**
Redtop	4	1.191	0.722	0.90	**2.813**	**2**
Reed Canary Grass	4	1.312	0.556	0.88	**2.748**	**3**
Russian Wild Rye	4	0.700	0.592	0.65	**1.942**	**6**
Tufted Hair Grass	4	1.215	0.467	0.77	**2.452**	**5**
Alkali Grass	8	1.036	0.486	1.00	**2.522**	**1**
Crested Wheatgrass	8	0.706	0.455	0.69	**1.851**	**4**
Redtop	8	1.126	0.664	0.65	**2.440**	**2**
Reed Canary Grass	8	0.982	0.494	0.88	**2.356**	**3**
Russian Wild Rye	8	0.494	0.349	0.75	**1.593**	**6**
Tufted Hair Grass	8	0.853	0.290	0.60	**1.743**	**5**
Alkali Grass	12	0.995	0.377	1.00	**2.372**	**1**
Crested Wheatgrass	12	0.421	0.213	0.40	**1.034**	**5**
Redtop	12	0.620	0.284	0.71	**1.614**	**2**
Reed Canary Grass	12	0.530	0.349	0.48	**1.359**	**3**
Russian Wild Rye	12	0.297	0.182	0.75	**1.229**	**4**
Tufted Hair Grass	12	0.384	0.111	0.48	**0.975**	**6**

Table 2.20: Overall ranking at each flood level in trial 1 using the LS means for below ground biomass.

Species	Flood Level (Weeks)	LS mean of Significant Response Variable	**Total**	**Rank**
		Root		
Alkali Grass	0	0.527	**0.527**	**3**
Crested Wheatgrass	0	0.767	**0.767**	**2**
Redtop	0	0.860	**0.860**	**1**
Reed Canary Grass	0	0.527	**0.527**	**3**
Russian Wild Rye	0	0.405	**0.405**	**5**
Tufted Hair Grass	0	0.406	**0.406**	**4**
Alkali Grass	1	0.502	**0.502**	**4**
Crested Wheatgrass	1	0.81	**0.81**	**1**
Redtop	1	0.523	**0.523**	**2**
Reed Canary Grass	1	0.426	**0.426**	**5**
Russian Wild Rye	1	0.514	**0.514**	**3**
Tufted Hair Grass	1	0.419	**0.419**	**6**
Alkali Grass	2	0.446	**0.446**	**3**
Crested Wheatgrass	2	0.597	**0.597**	**2**
Redtop	2	0.617	**0.617**	**1**
Reed Canary Grass	2	0.413	**0.413**	**4**
Russian Wild Rye	2	0.256	**0.256**	**6**
Tufted Hair Grass	2	0.376	**0.376**	**5**
Alkali Grass	4	0.261	**0.261**	**5**
Crested Wheatgrass	4	0.600	**0.600**	**2**
Redtop	4	0.555	**0.555**	**3**
Reed Canary Grass	4	0.618	**0.618**	**1**
Russian Wild Rye	4	0.255	**0.255**	**6**
Tufted Hair Grass	4	0.349	**0.349**	**4**

Table 2.21: Overall Ranking at each salt level in trial 2 using the LS means for above ground biomass, below ground biomass and survival.

Species	Salt Level (dS/m)	LS means of significant response variables			**Total**	**Rank**
		Shoot	Root	Survival		
Creeping Red Fescue	0	0.571	0.287	0.958	**1.816**	**3**
Tall Fescue	0	0.776	0.635	0.917	**2.328**	**1**
Timothy	0	0.714	0.388	0.833	**1.935**	**2**
Creeping Red Fescue	4	0.373	0.162	0.875	**1.410**	**2**
Tall Fescue	4	0.751	0.366	0.979	**2.096**	**1**
Timothy	4	0.430	0.176	0.771	**1.377**	**3**
Creeping Red Fescue	8	0.275	0.117	0.833	**1.225**	**2**
Tall Fescue	8	0.810	0.388	1.000	**2.198**	**1**
Timothy	8	0.339	0.105	0.708	**1.152**	**3**
Creeping Red Fescue	12	0.161	0.060	0.896	**1.117**	**2**
Tall Fescue	12	0.530	0.249	1.000	**1.779**	**1**
Timothy	12	0.156	0.051	0.292	**0.499**	**3**

Table 2.22: Overall Ranking at each flood level in trial 2 using the LS means for above ground biomass and below ground biomass.

Species	Flood Level (weeks)	LS means of significant response variables		Total	Rank
		Shoot	Root		
Creeping Red Fescue	0	0.317	1.534	**1.851**	1
Tall Fescue	0	0.567	0.343	**0.910**	2
Timothy	0	0.271	0.121	**0.392**	3
Creeping Red Fescue	1	0.313	1.590	**1.903**	1
Tall Fescue	1	0.579	0.435	**1.014**	2
Timothy	1	0.404	0.242	**0.646**	3
Creeping Red Fescue	2	0.343	0.173	**0.516**	3
Tall Fescue	2	0.678	0.437	**1.115**	1
Timothy	2	0.373	0.155	**0.528**	2
Creeping Red Fescue	4	0.406	0.140	**0.546**	3
Tall Fescue	4	1.042	0.423	**1.465**	1
Timothy	4	0.590	0.202	**0.792**	2

Based on the results of this experiment, in addition to species normally recommended for planting in saline areas such as Alkali Grass and Russian Wild Rye (along with several other species not tested in this experiment) (Wentz, 2003), species such as Tall Fescue, Creeping Red Fescue, Reed Canary Grass and Redtop may also be good candidates, as they were found to be tolerant of EC levels from 8-12 dS/m. The most beneficial species or species combination for use in any particular wetland-cropland ecotone depends on the primary desired use of the area (forage production, wetland protection or wildlife habitat), on the range and extent of the salt problem, and the area of land normally affected by flooding.

Because the effect of flooded conditions was not as deleterious as predicted, it is most important to select species for locations within the ecotone primarily based on salt

tolerance in all but the most flood prone areas (e.g. the ring of land surrounding open water) (Figure 2.28). The following figure (Figure 2.29) and table (Table 2.23) illustrate the most suitable species of those tested for use within different locations of the wetland-cropland ecotone depending on the extent of the salinity problem as well as the desired land use. The rankings for both overall flooding tolerance and overall salt tolerance of each plant species (Tables 2.19-2.22) were integrated in order to make species selections.

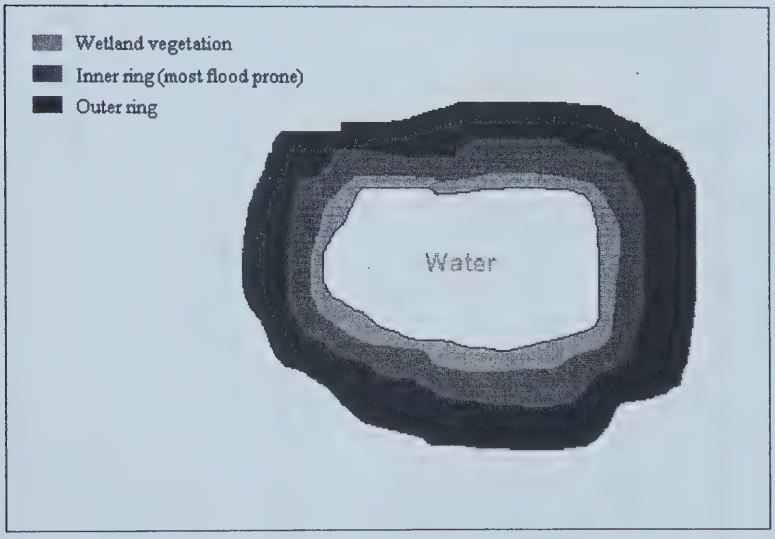

Figure 2.28: The wetland-cropland ecotone depicted as two main zones, the inner and outer rings surrounding the wetland.

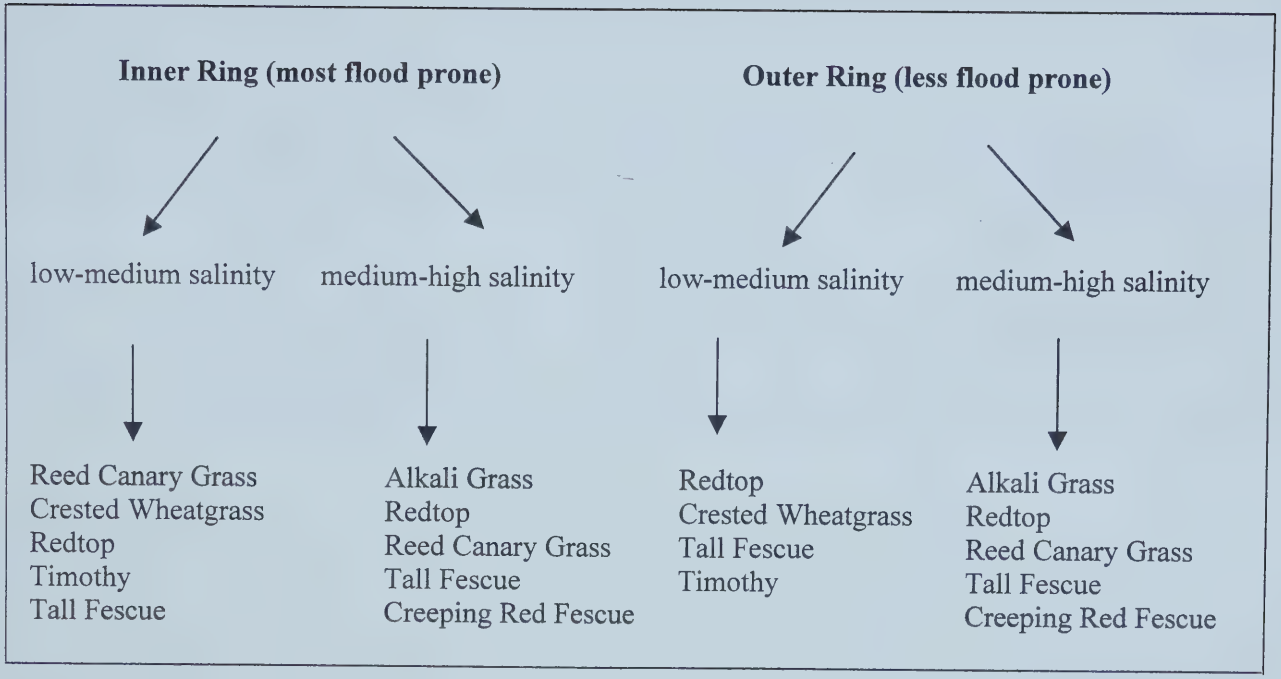

Figure 2.29: Most suitable species for planting within different locations within wetland-cropland ecotones.

Table 2.23: Most beneficial species for hay production, erosion control, wildlife / pasture use and salt tolerance.

Hay Production (Alberta Agriculture, 1981)	Erosion Control (Alberta Agriculture, 1981)	Wildlife / Pasture (Alberta Agriculture, 1981)	Most Salt Tolerant (from chapter 2 results)
Timothy	Tall Fescue	Russian Wild Rye	Alkali Grass
Tall Fescue	Redtop	Creeping Red Fescue	Redtop
Crested Wheatgrass	Reed Canary Grass	Crested Wheatgrass	Tall Fescue
Russian Wild Rye	Creeping Red Fescue	Tufted Hair Grass	Creeping Red Fescue
Reed Canary Grass	Tufted Hair Grass	Tall Fescue	
	Crested Wheatgrass		

2.4.2 Attributes of Species Tested

Alkali Grass and Tall Fescue were the two most salt tolerant species tested in this experiment; they experienced the least amount of biomass decrease with increasing salt concentrations as well as the greatest rate of survival over all other species at the higher salt levels.

In addition to being very salt tolerant, Tall Fescue was also the most flood tolerant species tested in the second trial. According to Hardy BBT Limited (1989), Tall Fescue has good potential for erosion control due to its deep roots and extensive rhizomes, is relatively palatable when properly managed and can produce excellent hay yields when grown with legumes and properly fertilized, however, it may not be completely winter hardy in all areas of Alberta (Alberta Agriculture, 1981). Tall Fescue was introduced to Canada from England in the 1920's (Alberta Agriculture, 1981).

Alkali Grass was not as flood tolerant as many of the other species tested in the first trial (it was ranked fifth under 4 weeks of flooding), although it is often found in moist saline depressions (Hardy BBT Limited, 1989). According to Hardy BBT (1989) Alkali Grass, while not normally abundant makes palatable hay; although stands are usually too sparse to obtain heavy yields. Alkali Grass is a plant native to western North America (Hardy BBT, 1989).

Reed Canary Grass was the most flood tolerant species tested in the first trial, and it also ranked third most tolerant at the two greatest salt levels. Reed Canary Grass is a native plant commonly found in wet places and is moderately drought tolerant (Hardy BBT Limited, 1989). The deep feeding roots and rhizomes (Alberta Agriculture, 1981) make it useful in erosion control (Hardy BBT Limited, 1989). Although it is

exceptionally high yielding for hay, it has a reputation for being of low quality, although this may not be the case if cut before heads emerge (Alberta Agriculture, 1981). Alkaloids present in the grass may limit animal gains in some instances (Alberta Agriculture, 1981)

Redtop was the second most salt tolerant species at the 12 dS/m level and the third most flood tolerant species after 4 weeks of flooding tested in the first trial. It was introduced from Europe, and reproduces from rhizomes, stolons and seeds (Stubbendieck et al., 1997). Redtop is commonly found in pastures and moist meadows, can withstand flooding for extended periods of time and can produce an acceptable quality hay if cut as the heads emerge (Stubbendieck et al. 1997).

Although Russian Wild Rye had very good survival at high salt concentrations it only ranked fourth most salt tolerant (due to low biomass production) and the least flood tolerant species tested in the first trial. In the literature it is classified as having high salt tolerance of up to 16 dS/m, but as difficult to establish because of poor seedling vigor (Alberta Agriculture, 1981; Hardy BBT Limited, 1989). This may explain the mediocre performance in this trial, as seedlings, not mature plants were used. Russian Wild Rye was introduced to Canada from Siberia in 1926 (Alberta Agriculture, 1981). It cures to a very palatable hay, and is very drought and cold tolerant (Alberta Agriculture 1981; Hardy BBT Limited, 1989).

Creeping Red Fescue was the second most salt tolerant and least flood tolerant species tested in the second trial. It is regarded as both a species native to Alberta, as well as escaped from cultivation (Hardy BBT Limited, 1989). Creeping Red Fescue is palatable throughout the growing season, and retains nutritive value even after freezing,

although due to its low growth habit, it is not suitable for use as hay (Alberta Agriculture, 1981; Hardy BBT Limited, 1989). It is a deep rooting plant species with an extensive fibrous root system, which makes it useful for soil building and erosion prevention (Hardy BBT Limited, 1989).

Tufted Hair Grass did very poorly, and ranked as the least salt tolerant and as fourth under the 4 weeks of flooding of the species tested in the first trial. It is a native plant that is normally found near sloughs, wet meadows and on stream banks, and reportedly has poor salt tolerance (Hardy BBT Limited, 1989). Tufted Hair Grass is fairly palatable and has been rated as fair to good for forage value for deer, game birds and small mammals, and is useful for erosion control (Hardy BBT Limited, 1989).

Timothy was ranked as the least salt tolerant and second most flood tolerant species tested in the second trial. It was introduced from Europe by early settlers and is noted for its excellent suitability to hay production (Alberta Agriculture, 1981). It is generally most abundant on moist, fertile, non-saline sites (Stubbendieck et al., 1997).

Crested Wheatgrass was ranked as the fifth most salt tolerant species at the 12 dS/m level, and as the second most flood tolerant species at the 4 week duration of flooding tested in the first trial. It was introduced to Canada from the former USSR in 1927 (Alberta Agriculture, 1981). Crested Wheatgrass is a very long-lived, competitive perennial that is reported to tolerate at least moderate to high levels of salinity (Hardy BBT Limited, 1989). It compares well with other grasses for quality and yield of hay, but should be harvested before heading as the quality drops markedly after that (Alberta Agriculture, 1981). Crested Wheatgrass is often used to control erosion because of its strong rooting and slightly rhizomatous habits, but it is not recommended for use in areas

where native prairie is to be maintained due to its invasive nature (Hardy BBT Limited, 1989).

Both Alfalfa and Bird's-foot Trefoil were all but completely killed off after being put into the coldroom in the second trial. This was likely due to the lack of recovery time necessary for the two legumes to develop new leaves and allocate carbohydrate resources below ground in order to survive dormancy (Alberta Agriculture, 1981). There is therefore no information on the combined effect of salinity and flooding for these species based on this experiment.

According to the literature, Bird's-foot Trefoil is very tolerant of waterlogged soils, withstanding several weeks of flooding (Alberta Agriculture, 1981). It is well suited to hay production, although it produces about one third less than alfalfa, and has a high water content which leads to difficulty in drying (Alberta Agriculture, 1981). Bird's-foot Trefoil was introduced from Europe, is moderately salt tolerant, fixes atmospheric nitrogen and is useful for erosion control (Alberta Agriculture, 1981; Hardy BBT Limited, 1989).

Alfalfa, an introduced plant, reportedly has medium salt tolerance of up to 8 dS/m (Hardy BBT Limited, 1989) after establishment, although it has reportedly low flooding tolerance throughout the growing season (Alberta Agriculture, 1981). With roots extending up to 3 to 9 m (Alberta Agriculture, 1981), high water use requirement and extended growing season, it is often recommended for planting in ground-water recharge areas in areas affected by salinity (Eilers et al., 1995; Wentz and King, 1999). Alfalfa is the preferred hay crop in Alberta with a high forage yield and high protein content (Alberta Agriculture, 1981; Hardy BBT Limited, 1989).

2.5 Conclusions

This experiment was able to meet the objective of determining the range of salt and flood tolerance for 9 of the 11 species tested. Because of the differentiation in performance (survival, above and below ground biomass) between species at different levels of salinity and flooding, the hypothesis that some of the species tested would perform better than others under different levels of salinity and flooding was not rejected. The hypothesis of increased salt concentrations reducing survival and growth was not rejected because of distinct decreases in survival and biomass production at the higher levels of salt. However, due to increased growth under longer durations of flooding, the hypothesis that increased flooding durations would have a negative impact on above and below ground biomass production was rejected.

As mentioned earlier, while this experiment only tested growth and survival of the plant species for a maximum of 5 months, according to Blum (1985), salt tolerance of seedlings is highly predictive of the response of adult plants to salinity. Because salinity had the greatest impact on plant success, it is likely more important to select species with high salt tolerance for use in all but the most flood-prone areas (inner ring) within salt-affected wetland-cropland ecotones. Alkali Grass, Tall Fescue, Redtop and Creeping Red Fescue were the most "successful" species tested at the higher levels of salt, having better survival rates and greater biomass. These species are likely better suited to the more saline areas within the wetland-cropland ecotone than the other, less tolerant species. In non- or weakly saline areas prone to longer durations of flooding, Tall Fescue, Timothy, Reed Canary Grass and Crested Wheatgrass were the most "successful" species having the greatest survival rates and higher biomass production. The most effective species for

use within the wetland-cropland ecotone will also depend on the desired primary land use, as all of the species tested have some positive attributes that could be useful within certain areas.

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3. The Effects of Soil Texture, Salinity and Flooding on Two Salt Tolerant Forage Species

3.1 Introduction

In the previous chapter, salt and flooding treatments were applied to 11 different plant species in sand-filled pots in order to select a few forage species with suitable ranges of salt and flood tolerance for possible use in wetland-cropland ecotones. While the effects of increasing salinity were predictable from the literature, with increasing salt levels decreasing biomass for all species tested, the impact of longer flooding durations did not have the expected adverse effects on biomass. It was thought that flooded conditions, especially for longer durations, would lead to oxygen deficiency within the growth medium, inhibiting plant growth and decreasing dry matter yields as stated in Drew (1991), Lessmann et al. (1997) and Dennis et al. (2000). As reported in chapter 2, longer flooding durations (of up to four weeks) actually increased overall above ground biomass in both trials, and only decreased overall below ground biomass in the first trial. Increased durations of flooding did not adversely affect the survival of the species tested. When the results obtained in the first experiment showed plant growth stimulation not inhibition, it was hypothesized that the reason may have been due to the use of sand as the growth medium with large particle size and pore size allowing for solution movement through the root zone as well as a rapid recovery of aeration after flooding was terminated. Another explanation could have been due to the poor water-holding capacity of sand (Hausenbuiller, 1985). Even though the plants in chapter 2 were watered regularly when the sand began to dry out, it was possible that moisture was a factor limiting growth. If this were the case, when the plants were flooded with the appropriate

salt treatment, any moisture limitations would have been removed, thus improving growth; this potential issue was eliminated by increasing watering frequency in this trial.

Particle size, and therefore soil texture, impacts soil physical properties such as water-holding capacity, soil structure, porosity and hydraulic conductivity (Naeth et al., 1991). In general, coarser particles (sand-sized, from 0.05-2.00 mm) increase pore size as well as permeability to air and water (Hausenbuiller, 1985). Finer particles (silt sized, 0.002-0.05 mm and clay sized, <0.002 mm) will often form compound particles or aggregates that have increased overall porosity (inter and intra aggregate pores) but with decreased pore size (Hausenbuiller, 1985; Naeth et al., 1991). In general, soils with a high sand fraction do not aggregate well, have poor water holding capacities but are well aerated. Soils high in clay content may have poor drainage and aeration unless the soil is well aggregated, which may mitigate the very small pore size through the formation of larger inter-aggregate pores. Silty or loam soils are generally the most productive because of good aggregation, drainage, aeration and water holding capacity (Naeth et al., 1991).

In order to determine if the coarse textured growth medium was the reason for the stimulatory growth effect with longer flooding durations and to determine what effect, if any, different soil textures have on the salt and flooding tolerance of two salt tolerant plant species, salt and flooding treatments were applied to Alkali Grass and Tall Fescue grown in loam, clay and sand. Another purpose was to determine if the plant performance in sand was a good predictor of plant performance in different textured soils. The two plant species used in this experiment were found to be very salt tolerant in the

previous experiment, with the greatest survival rates and least amount of biomass reduction at the 12 dS/m treatment level.

It was hypothesized that due to smaller particle and pore size, plants grown in clay soils would be more negatively affected (decreased above and below ground biomass production) by longer durations of flooding than those plants grown in the loam textured soils, which would be more negatively affected than those grown in sand. It was also hypothesized that the general trends expressed by plants grown in the two different soils (clay and loam textured soils) would be similar to those seen in chapter 2, where increasing salt concentrations decreased survival, above and below ground biomass production.

3.2 Methods

3.2.1 Growth Media Preparation

The soil with high clay content was collected from a farm near Villeneuve, Alberta (approximately 53° 43′ N, 113° 53′ W) from the surface 20 cm. The loam soil was collected from the Breton Classical Plots near Breton, Alberta (approximately 53° 06′ N, 114° 26′ W) from the surface 20 cm. Both the clay and loam soils were air dried and sieved to 6 mm and then autoclaved to kill any weeds. The sand was supplied by Belair Sand and Gravel from a location near Ft. Saskatchewan, Alberta (approximately 53° 44′ N and 113° 12′ W). The sand was sieved to 2 mm and was then autoclaved. Properties of each growth medium are described in Table 3.1.

Table 3.1: Physical characteristics of the sand, loam and clay soils used as growth media.

Characteristic	Clay soil	Loam soil	Sand
% sand	23.2	34.6	96.0
% silt	36.7	41.9	4.0
% clay	40.1	23.5	<0.1
PH	5.6	6.5	8.4
EC (dS/m)	1.2	0.5	0.3
Organic matter (%)	10.2	3.2	<0.1
N (Nitrate) (mg/kg)	77.8	17.6	1.9
P (mg/kg)	38.0	11.0	<5.0
K (mg/kg)	422.0	280.0	28.0
S (Sulphate) (mg/kg)	>20.0	>20.0	10.0
Ca (mg/kg)	2500.0	2850.0	1670.0
Na (mg/kg)	658.0	25.0	12.0
Mg (mg/kg)	842.0	331.0	60.1
Fe (mg/kg)	198.0	68.0	42.0
Cu (mg/kg)	1.7	0.6	0.3
Zn (mg/kg)	8.2	13.4	2.2
B (mg/kg)	1.7	0.5	<0.1
Mn (mg/kg)	93.5	44.7	16.4
Cl (mg/kg)	109.0	18.1	6.0

3.2.2 Experimental Design

In order to establish the plants under saline conditions, this experiment was set up in a greenhouse with an approximate temperature range of 18° C night and 22° C day and a 16-hour photoperiod in order to apply the increasing salt treatments to each species*soil texture combination. Plants were subjected to salt treatments for 8 weeks prior to initiating the flooding component. Salt treatments included increasing levels of sodium and magnesium sulfates (0, 4, 8 and 12 dS/m), with twelve replicates for each salt*soil texture*species combination for a total of 288 pots. These twelve replicates were further divided into four flooding treatments with three replicates each for the species*texture*salt combination after the 8-week period of plant establishment under saline conditions. For ease of salt treatment application and in order to minimize human

error, salt treatments were randomly placed as blocks on the greenhouse bench. The pots containing individual plant species in each of the three soil textures were randomly placed within these salt blocks.

Each of the 288 6-inch (15.2 cm diameter) plant pots with 5 holes in the bottom was lined with Weed-Shield® landscape fabric and filled with approximately 1.5 L of growth media (sand, loam or clay soil). The filled pots were saturated with one of the salt solutions until the EC of the leachate out the pot bottom, measured with the Oakton PC 300 series portable pH/ electrical conductivity/ temperature meter, was equal to that of the input treatment. Treatments included a control of half strength Hoagland's solution (Hoagland and Arnon, 1938 in Hewitt, 1966) (Table 3.2) and three salt solutions consisting of half strength Hoagland's solution with added $MgSO_4$ and Na_2SO_4 salts in a 2:1 ratio (adapted from Rogers and West, 1993). Hoagland's solution was used as it is a complete nutrient solution including the macro and micronutrients necessary for plant growth, and although the loam and clay soils had adequate nutrient levels according to the analyses completed by Norwest Labs, the sand did not. So, in order to have more controlled conditions, all treatments for three growth media were prepared with the half strength Hoagland's solution. Each pot was then seeded with a single plant species (Tall Fescue or Alkali Grass), and after the seedlings had emerged, they were thinned to four seedlings per pot for a total of 1152 plants. Pots were watered with 250 mL of one of the three treatment solutions or the control when required (as soil began to dry out), as assessed for each soil texture individually, (approximately 2-5 times per week) over the following two months. The different water-holding capacities/drainage of the soil textures necessitated individual assessments (e.g., the sand dried out far faster than the

clay and loam soils). In order to minimize the chance that moisture conditions were limiting, pots containing sand were watered more often than in chapter 2. All pots of the same soil texture were watered at the same time. The EC of the leachate was monitored on a regular basis to ensure the salt level of the growth media was within the range for each particular treatment. If the EC of the leachate increased out of the range of acceptability (+1.0 dS/m), all of the pots were watered with a solution of half-strength Hoagland's solution with deionized water to drop the EC back into acceptable range (+/- 1.0 dS/m). After two months the plant establishment phase was completed.

The number of live plants in each pot were counted, and all plants (up to four seedlings per pot) were harvested 5 cm above the sand surface. Shoot samples were dried at 65° C until biomass reached a constant weight (approximately 48 hours); biomass was then measured and recorded.

Table 3.2: Full Strength Hoagland's solution constituents and concentrations.

Macronutrient Stock Solution	Stock Concentration (g/L)	mL of stock/ L of solution	Final Concentration
KNO_3	101.1	6	6 mM
$Ca(NO_3)_2$	164.1	4	4 mM
$NH_4H_2PO_4$	115.0	1	1 mM
$MgSO_4$	120.4	2	2 mM
Micronutrient Stock Solution		1	1 mM
H_3BO_3	2.9		0.5 mg/L B
$MnCl_2*4H_2O$	1.8		0.5 mg/L Mn
$ZnSO_4*7H_2O$	0.2		0.05 mg/L Zn
$CuSO_4*5H_2O$	0.1		0.02 mg/L Cu
85% Mo acid	0.02		0.01 mg/L Mo
Fe-EDTA	1.0		1 mg/L

Table 3.3: EC, pH and the amount of Na_2SO_4 and $MgSO_4$ required to produce treatment electrical conductivities.

Treatment	EC (dS/m)	pH	Na_2SO_4 (g/L)	$MgSO_4$ (g/L)
Control	0.0	7.5	0.00	0.0
4 dS/m	4.0	6.6	1.18	2.0
8 dS/m	8.0	6.6	2.95	5.0
12 dS/m	12.0	6.4	5.31	9.0

After harvesting the biomass from the plant establishment phase the flooding trial was started. Unlike in chapter 2, plants in this experiment were not placed in the coldroom to induce a dormant-like state. In chapter 2, two of the species tested had a very high death rate (90%) during the dormancy period, so it was decided that in order to

obtain the most data in this experiment we would only test the two most salt tolerant species, and we would not attempt to induce a dormant-like state.

This part of the experiment was set up as a split plot design in a greenhouse with an approximate temperature range of 18° C night and 22° C day and a 16-hour photoperiod. The purpose of this part of the experiment was to compare the above and below ground biomass production of the two species grown in 3 different growth media of different textures under increasing levels of sodium and magnesium sulfates (0, 4, 8, and 12 dS/m), and increasing durations of flooding (saturation up to the soil surface without free water above the surface for 0, 1, 2, 4 weeks) with three replicates for each salt*flood*species*texture combination. For this part of the trial, the greenhouse bench was set up into three blocks (replicates), where the block was considered to be the whole plot. Rubbermaid® bins containing salt*flooding treatments, considered as part of the whole plot, were randomly placed within these blocks. Plant species and texture were considered as the sub-plot. Flooding treatments included a control of 0 weeks, as well as durations of 1, 2 and 4 weeks under flooded conditions with the appropriate salt treatment solution. Pots were separated into 3 replicates for each of the species*texture*salt*flooding treatment combinations, and were then placed in three, 35-L Rubbermaid® bins (one bin for each replicate) containing treatment solutions. Each bin contained a single salt solution (0, 4, 8, and 12 dS/m), and all textures*species combinations. The pots placed inside each bin were flooded up to the surface of the growth medium. Non-flooded treatments (controls) were watered when dry with the appropriate treatment solution (0, 4, 8 or 12 dS/m). In order to account for water lost through evaporation and transpiration, water was added when required in order to

maintain EC and the desired level of flooding (St. Omer and Schlesinger, 1980). After each flooding treatment was completed, pots were removed from the bins and then watered when required with appropriate treatment solution until all 3 flooding treatments (durations of 1, 2 and 4 weeks) were completed.

After the flooding component was completed, the number of surviving plants were counted. All plants (up to four seedlings per pot) were harvested at the soil surface. Roots were washed free of growth medium and both roots and shoots samples were dried at 65° C until biomass reached a constant weight (approximately 48 hours); biomass was measured and recorded. Root biomass is expressed as an average calculated by dividing the amount of root biomass by number of surviving plants per pot, as it was not possible to separate roots from individual plants.

3.2.3 Statistical Analyses

This part of the experiment was set up as a four-factor factorial, split plot design, with block and the salt*flooding treatments considered as the main plot. The 4 factors were salt, flood, soil texture and species; salt had 4 levels (electrical conductivities of approximately 0 dS/m, 4 dS/m, 8 dS/m, 12 dS/m), flood had 4 levels (0, 1, 2 and 4 week durations), texture had three levels (sand, clay and loam) and species had 2 levels (Alkali Grass and Tall Fescue). Block, salt and flood effects (whole plot) were tested with the interaction (block*salt*flood) as the error term. All other effects and interactions (sub-plot) were tested with the natural error term. Probabilities and F-values reported for species and salt are the type III, calculated using the specified error term. Means, LS means, standard errors, ANOVA were calculated using GLM (general linear model); Chi-

Squared maximum likelihood analysis of variance were calculated using CATMOD (categorical model). Both procedures were carried out using the SAS 8.0 statistical package (1999-2000). Normality was tested using the Shapiro-Wilks test within UNIVARIATE (SAS, 1999-2000). Root data was not normally distributed, however transformations did not improve normality. It was assumed that the ANOVA procedure, especially with large sample size was robust enough to handle the data. Post-hoc multiple comparisons of significant response variables and interactions were completed using the Tukey-Kramer adjusted pairwise comparisons of the LS means. Salt, flood, texture, species and interaction effects were considered significant at α=0.05. Species, salt, texture and flood were completely crossed, fixed effects.

3.3 Results

As the effects of salt, flooding, species and the interactions of the three have already been discussed in chapter 2, the results presented in this chapter focus on the effect of texture and significant interactions containing texture, on above ground biomass, below ground production and root to shoot ratios. The effects of salt, flooding and species follow very similar trends with all response variables in this trial as in chapter 2, with the exception of survival.

3.3.1 Survival

In this trial, we used Alkali Grass and Tall Fescue, the two most salt tolerant species from chapter 2; none of the main effects had a significant effect on survival (Table 3.4). This is not surprising as only one of the 1152 plants died.

Table 3.4: Maximum likelihood Analysis of Variance for survival.

Sources of Variation	D.F.	Chi-Square	Pr>Chi Square
Salt	3	0.97	0.8078
Flood	3	0.97	0.8078
Species	1	0.45	0.5021
Texture	2	0.75	0.6880
Species*Texture	2	0.01	0.9967
Texture*Salt	6	0.01	1.0000
Texture*Flood	6	0.01	1.0000
Texture*Salt*Flood	18	0.09	1.0000
Species*Texture*Flood	6	0.03	1.0000
Species*Texture*Salt	6	0.03	1.0000

3.3.2 Above Ground Biomass

The amount of above ground biomass produced in the clay soil was significantly greater than the amount produced in the loam soil, which was significantly greater than the amount produced in the sand (Figure 3.1).

The salt*texture interaction shows a similar relationship, where the amount of biomass produced in the clay soil was significantly greater than in the loam which was significantly greater than that produced in the sand, regardless of the salt treatment (Figure 3.2). The amount of above ground biomass produced generally decreased as the salt concentration increased, although there was no significance between salt treatments 0 dS/m and 4 dS/m or between 8 dS/m and 12 dS/m for any of the soil textures. In both the sand and loam textures, there was also no significant difference between 12 dS/m and the 0 dS/m and 4 dS/m.

The effect of texture on the flood*texture interaction is one where clay produced significantly more above ground biomass than loam which produced significantly more than sand under all flooding durations (Figure 3.3). There was a trend of increased above

ground biomass with increased flood durations for all soil textures. Plants subjected to the four weeks of flooding produced significantly more biomass than all other treatments in both the clay and loam soils. There was no significant difference in the amount of above ground biomass between 2 and 4 weeks of flooding in the sand.

The salt*flood*texture interaction is one where biomass generally increased with flood duration, regardless of texture or salt level, and one where plants grown in clay produced significantly more above ground biomass than plants grown in loam which produced significantly more than plants in sand (Figure 3.4). There was an overall decrease in biomass with the higher salt levels, although the effect of the higher salt concentrations appears to be mitigated by longer flood durations. In some cases, longer flooded durations at higher salt concentrations produced more biomass than shorter flood durations at lower levels of salt.

Table 3.5: Analysis of Variance for above ground biomass.

Sources of Variation	D.F.	F Value	Pr>F
Block	2	9.94	0.0005
Salt	3	15.39	<0.0001
Flood	3	29.97	<0.0001
Species	1	21.73	<0.0001
Texture	2	563.41	<0.0001
Error = Block*Salt*Flood	30	2.98	<0.0001
Flood*Species	3	6.13	0.0004
Salt*Species	3	15.00	<0.0001
Flood*Texture	6	3.40	0.0025
Salt*Texture	6	3.16	0.0045
Texture*Species	2	2.87	0.0572
Salt*Flood*Species	9	2.11	0.0266
Salt*Texture*Species	6	0.73	0.6235
Salt*Flood*Texture	18	1.96	0.0098
Flood*Texture*Species	6	1.19	0.3105
Salt*Flood*Texture*Species	18	1.15	0.2941

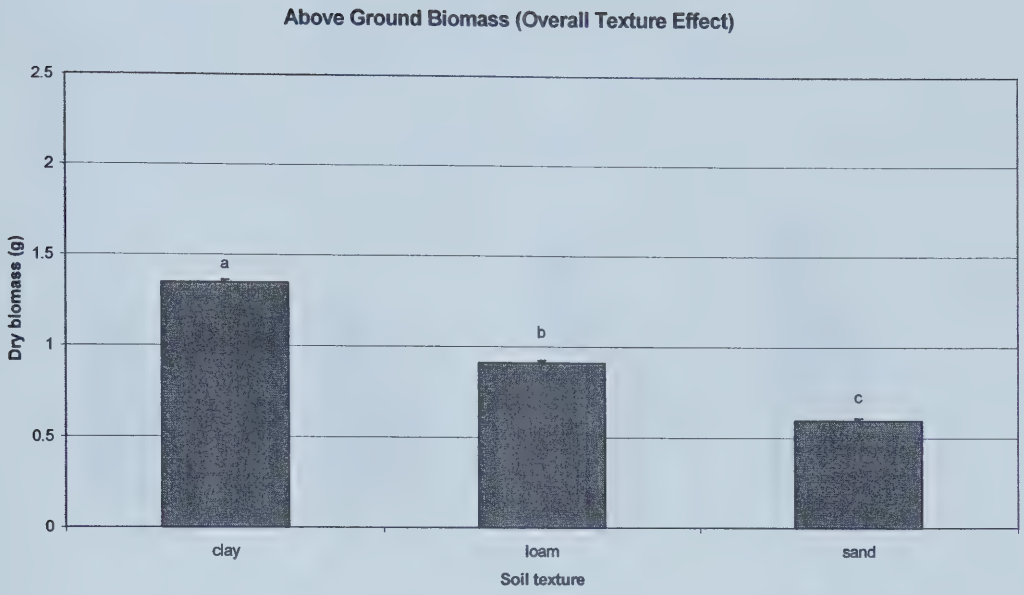

Figure 3.1: Average (LS means) above ground biomass produced per plant in each soil texture. Bars include both species at all salt*flooding treatments. Bars with common letters are not significantly different (α =0.05).

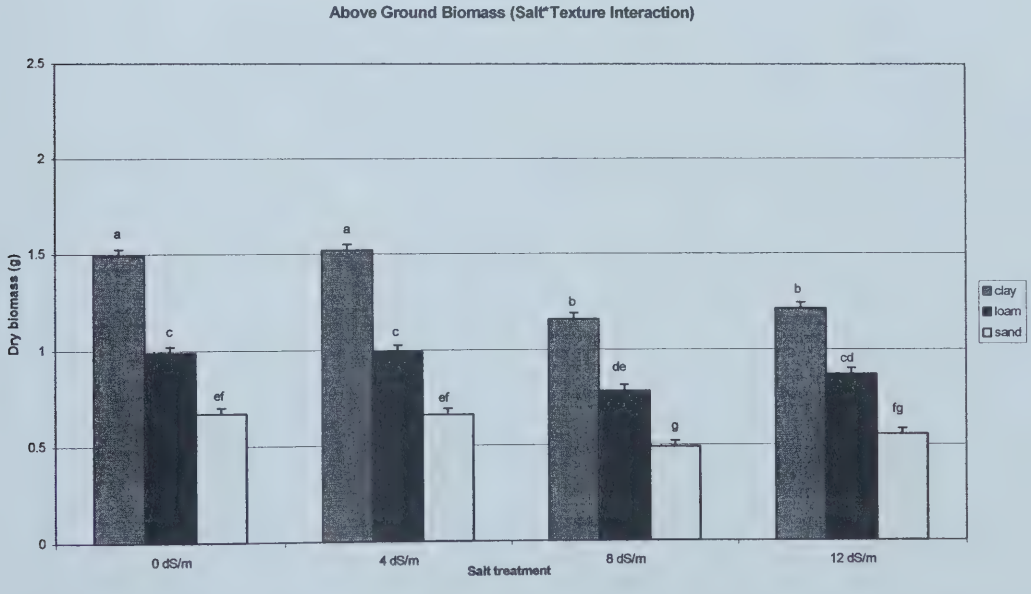

Figure 3.2: Average (LS means) above ground biomass produced per plant in each soil texture at each salt level. Bars include both species at all flooding treatments. Bars with common letters are not significantly different (α =0.05).

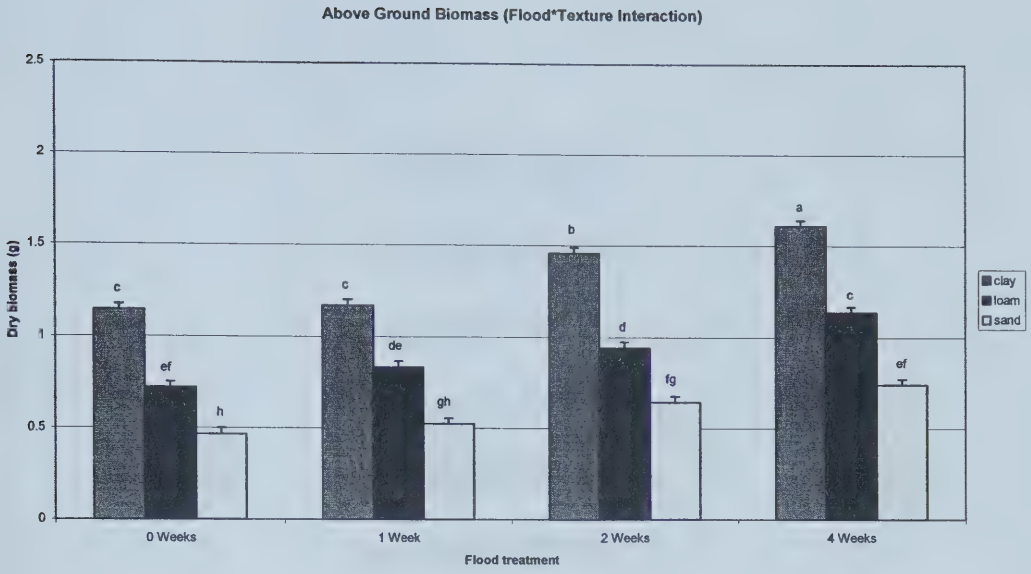

Figure 3.3: Average (LS means) above ground biomass produced per plant in each soil texture at each flood level. Bars include both species at all salt treatments. Bars with common letters are not significantly different (α =0.05).

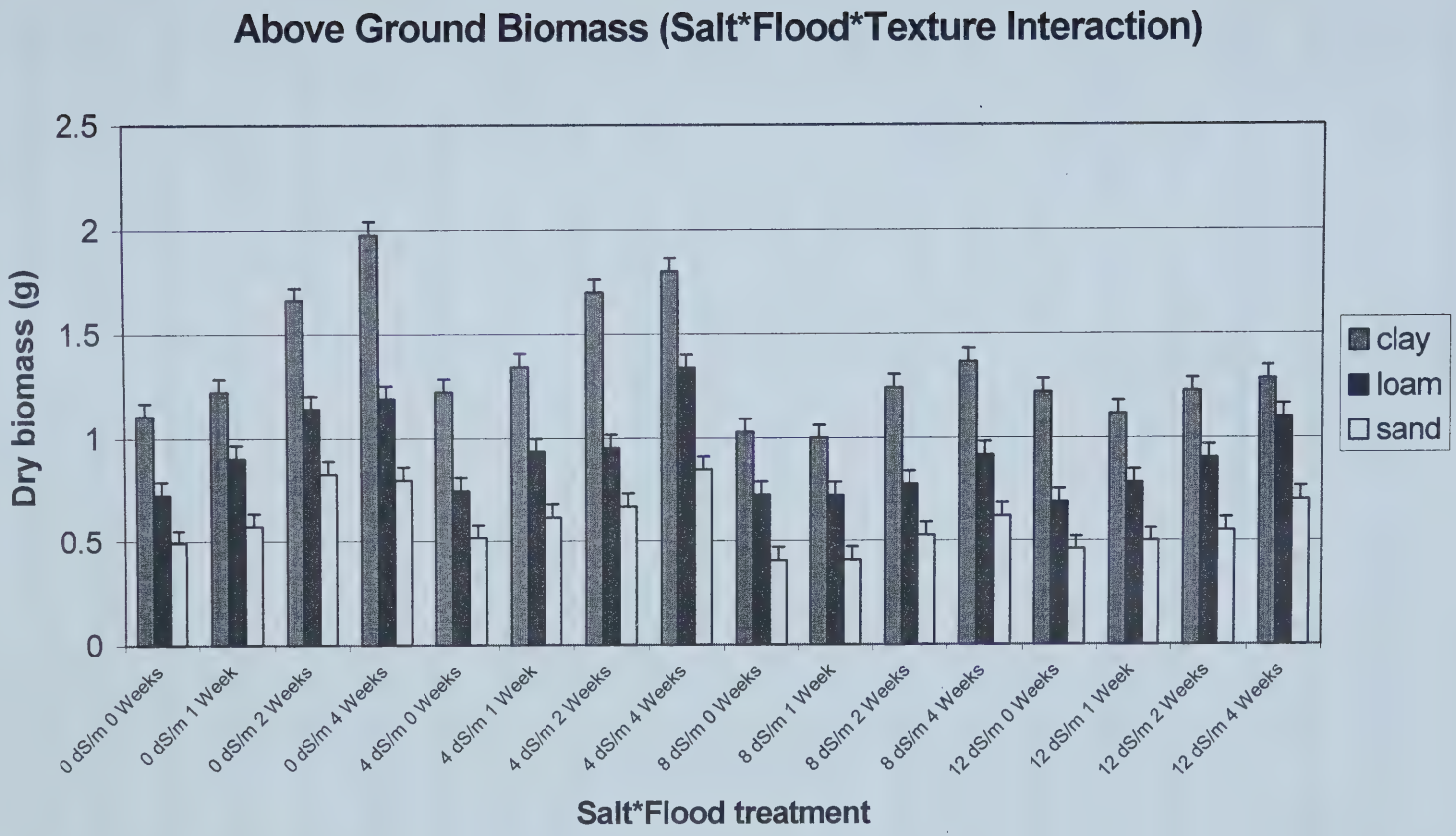

Figure 3.4: Average (LS means) above ground biomass produced per plant in each soil texture at each salt*flood level. Bars include both species. Bars with common letters are not significantly different (α =0.05).

3.3.3 Below Ground Biomass

The effect of texture is one where plants grown in clay had significantly higher below ground biomass than those grown in sand, which produced significantly more biomass than those grown in loam (Figure 3.5).

The salt*texture effect is one where plants grown in the higher salt levels generally produced less below ground biomass than those in the lower salt levels (Figure 3.6). Clay produced significantly more below ground biomass than both sand and loam in all salt treatments, except the 0 dS/m level, where there was no difference between the sand and the clay soil. Sand produced significantly more biomass than loam at the 0 dS/m salt level, but there were no differences between the two at all other salt levels. In general, there was significantly more below ground biomass produced at 4 dS/m than at 0 dS/m, both of which produced significantly more below ground biomass than 12 dS/m, which in turn produced more than at 8 dS/m. There were two exceptions, the first was where sand produced more at 0 dS/m than at 4 dS/m, and the second was where there was no significant difference between the 8 dS/m and the 12 dS/m treatment in the loam soil.

The flood*texture interaction is one where clay produced significantly more below ground biomass than both sand and loam textures except under the second flooding treatment (1 week) where sand and clay were not significantly different (Figure 3.7). Sand and loam textures did not generally differ, except at 1 week of flooding where sand produced more below ground biomass than loam. There were no significant changes in below ground biomass for the loam soil over all flood durations. Plants grown in clay produced significantly more below ground biomass at 2 weeks of flooding than all other

flood durations. Plants in both the 1 week and 2 weeks of flooding treatments in sand produced more below ground biomass than 0 and 4 weeks in sand.

The texture*species interaction shows that Tall Fescue produced more below ground biomass than Alkali Grass in all soil textures (Figure 3.8). Alkali Grass produced significantly more below ground biomass in the clay soil than in sand, which produced more below ground biomass than in the loam soil. Tall Fescue produced significantly more biomass in the clay than in both the loam and sand.

In the salt*species*texture interaction Tall Fescue produced significantly more below ground biomass than Alkali Grass at all salt levels, although the magnitude of difference decreased as the salt level increased (Figure 3.9). In general, the higher salt levels produced less biomass than the lower salt levels.

The flood*species*texture interaction is one where increasing flood durations increased below ground biomass for Tall Fescue (Figure 3.10). The below ground biomass for Alkali Grass was not significantly affected except at 2 weeks of flooding in the clay texture, where below ground biomass was increased over all other treatments for Alkali Grass. Alkali Grass under 2 weeks of flooding in the clay texture produced significantly more below ground biomass than all other treatment*textures except for 1 week of flooding in sand.

Increasing salt concentrations in the salt*flood*texture interaction generally decreased the amount of below ground biomass produced (Figure 3.11). Clay generally produced more below ground biomass than sand and loam, except at the 0 dS/m salt and 0 weeks of flooding and the 0 dS/m salt and 1 week of flooding where sand produced more.

The four way interaction between species*salt*flood*texture was significant for the amount of below ground biomass produced, which means that the amount of root biomass produced for at least one species was significantly affected by the interaction of salt, flooding and texture together. This is a very complicated relationship to illustrate and interpret, so the results are presented in Table A-4 in the appendix rather than in graphs.

Table 3.6: Analysis of Variance for below ground biomass.

Sources of Variation	D.F.	F Value	Pr>F
Block	2	1.96	0.1582
Salt	3	22.21	<0.0001
Flood	3	1.89	0.1533
Species	1	2679.11	<0.0001
Texture	2	177.06	<0.0001
Error = Block*Salt*Flood	30	20.45	<0.0001
Flood*Species	3	19.12	<0.0001
Salt*Species	3	113.59	<0.0001
Flood*Texture	6	14.95	<0.0001
Salt*Texture	6	12.97	<0.0001
Texture*Species	2	25.97	<0.0001
Salt*Flood*Species	9	6.71	<0.0001
Salt*Texture*Species	6	4.17	0.0004
Salt*Flood*Texture	18	9.22	<0.0001
Flood*Texture*Species	6	4.28	0.0003
Salt*Flood*Texture*Species	18	11.28	<0.0001

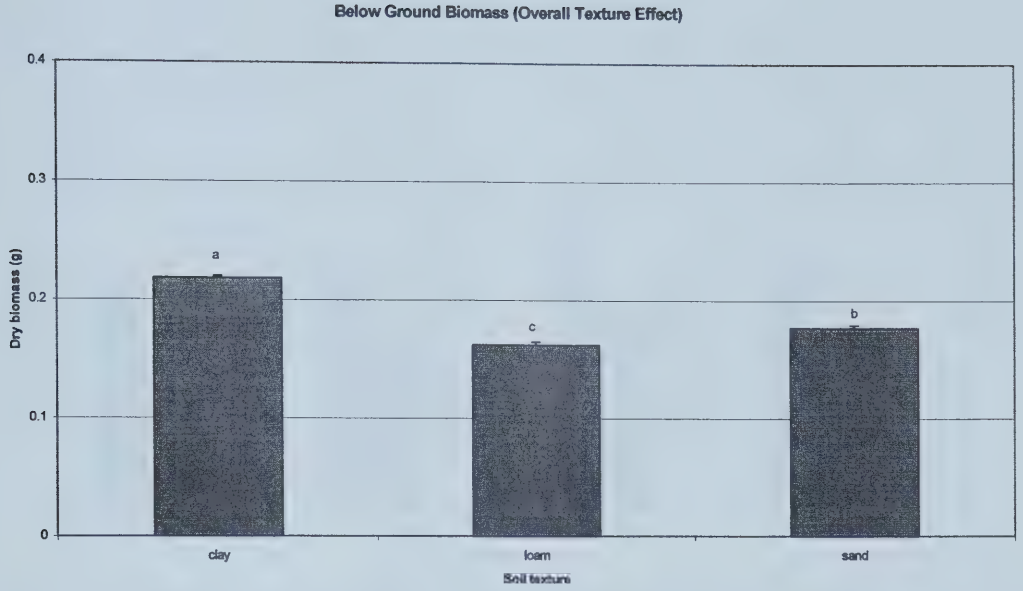

Figure 3.5: Average amount (LS means) of average below ground biomass produced in each soil texture (total amount below ground biomass per pot/number of survived plants per pot). Bars include both species at all salt*flooding treatments. Bars with common letters are not significantly different (α =0.05).

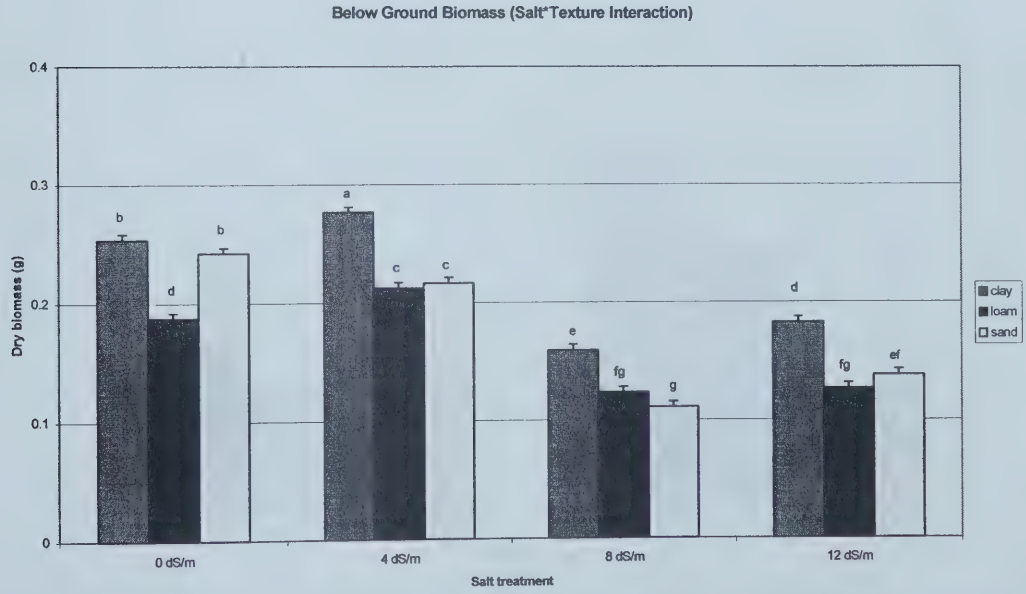

Figure 3.6: Average amount (LS means) of average below ground biomass produced in each soil texture at each salt treatment (total amount below ground biomass per pot/number of survived plants per pot). Bars include both species at all flooding treatments. Bars with common letters are not significantly different (α =0.05).

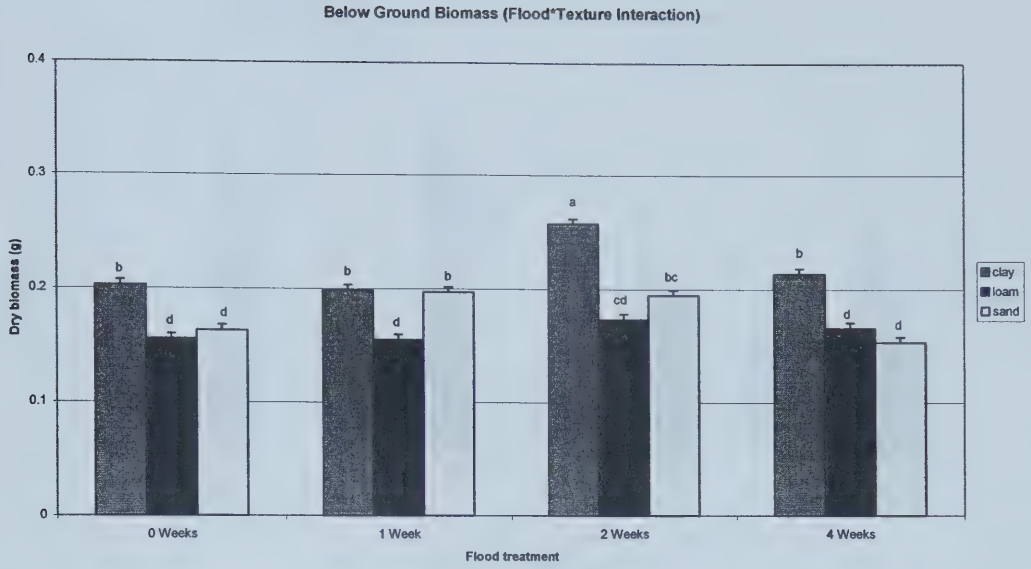

Figure 3.7: Average amount (LS means) of average below ground biomass produced in each soil texture at each flooding duration (total amount below ground biomass per pot/number of survived plants per pot). Bars include both species at all salt treatments. Bars with common letters are not significantly different (α =0.05).

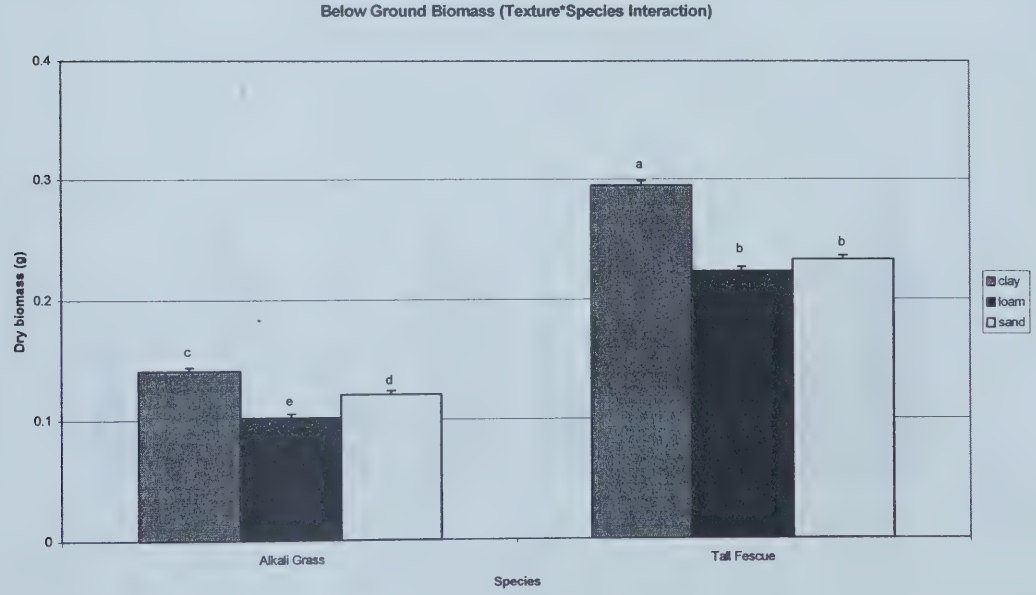

Figure 3.8: Average amount (LS means) of average below ground biomass produced in each soil texture by each species (total amount below ground biomass per pot/number of survived plants per pot). Bars include all salt*flood treatments. Bars with common letters are not significantly different (α =0.05).

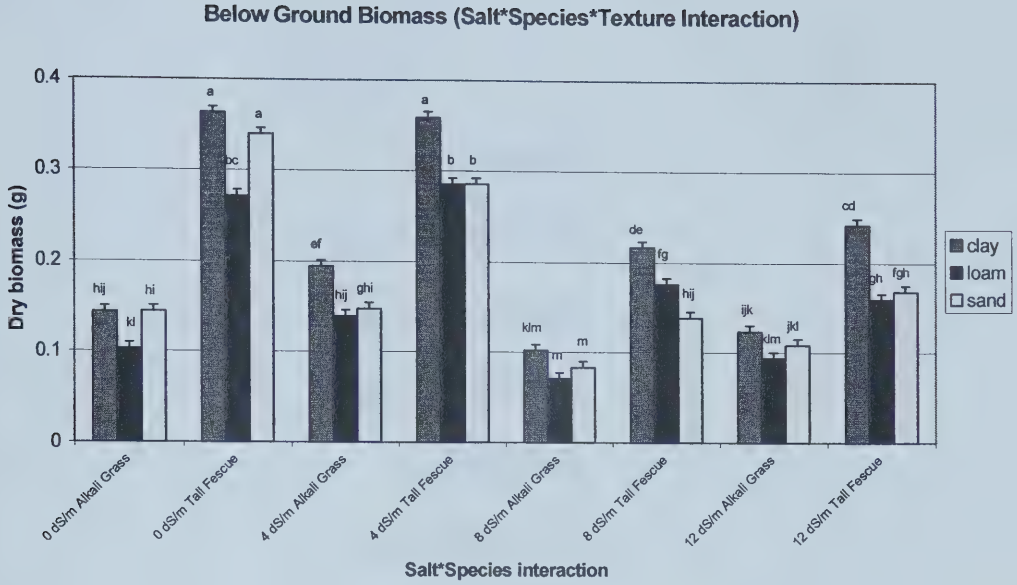

Figure 3.9: Average amount (LS means) of average below ground biomass produced in each soil texture by each species under all salt treatments (total amount below ground biomass per pot/number of survived plants per pot). Bars include all flood treatments. Bars with common letters are not significantly different (α =0.05).

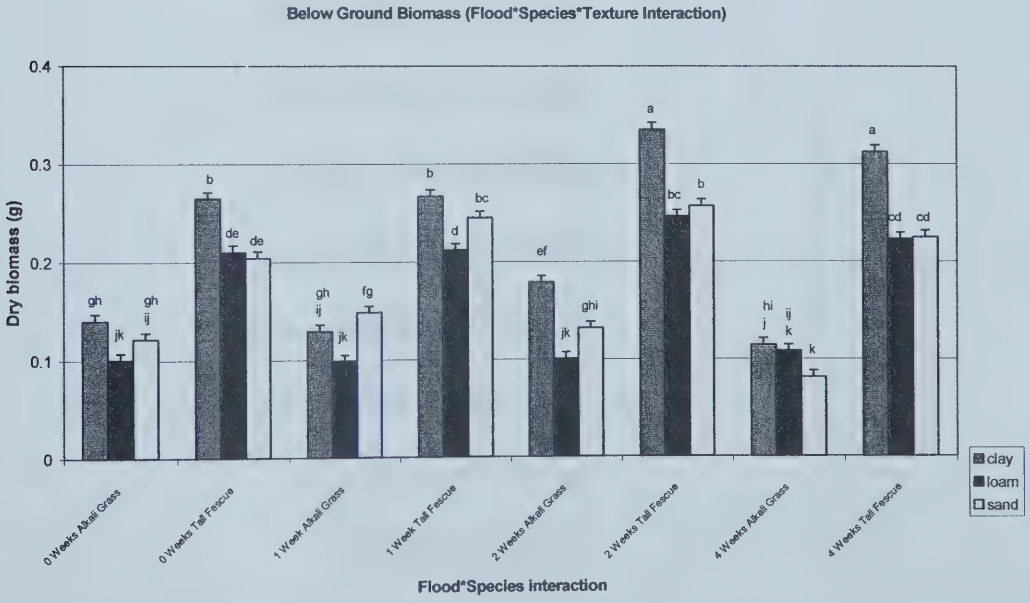

Figure 3.10: Average amount (LS means) of average below ground biomass produced in each soil texture by each species under all flood treatments (total amount below ground biomass per pot/number of survived plants per pot). Bars include all salt treatments. Bars with common letters are not significantly different (α =0.05).

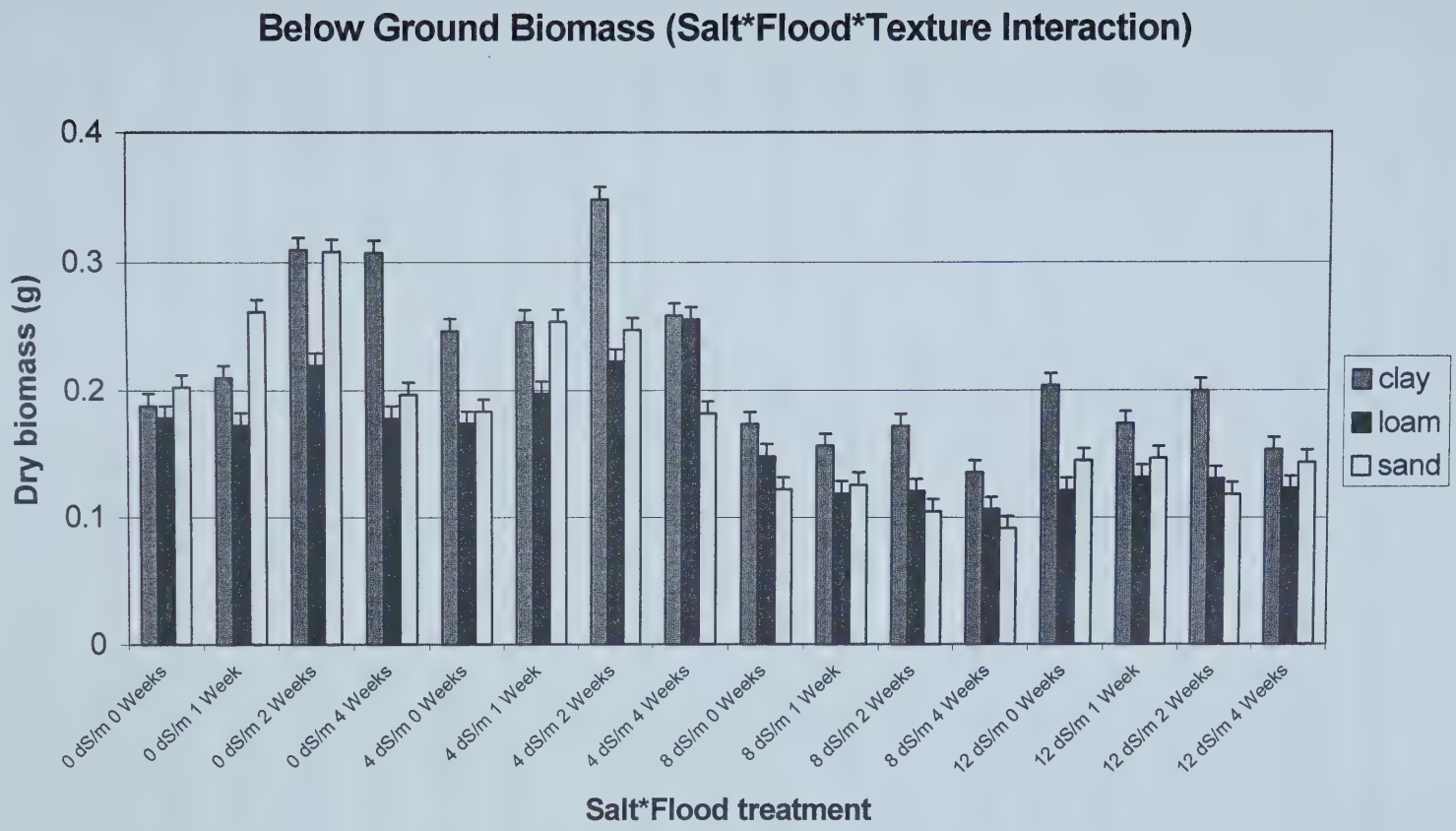

Figure 3.11: Average amount (LS means) of average below ground biomass produced in each soil texture at each salt*flood level (total amount below ground biomass per pot/number of survived plants per pot). Bars include both species. Bars with common letters are not significantly different (α =0.05).

3.3.4 Root to Shoot Ratio

The overall texture effect is one where plants grown in sand produced a higher root to shoot ratio than those grown in loam, which produced a higher ratio than those in clay (Figure 3.12).

In the salt*texture interaction for root to shoot ratio, plants in sand produced a greater ratio than those in loam and clay for all salt treatments (Figure 3.13). The ratio produced for clay and loam were equal for all salt treatments. In the sand, plants subjected to the 0 dS/m and the 4 dS/m salt treatments produced a higher root to shoot ratio than those in the 12 dS/m and 8 dS/m treatments. In the clay textured soil, plants subjected to the 4 dS/m treatment produced a significantly greater ratio than that produced by plants in the 8 dS/m; there were no other differences in the clay*salt treatments. In the loam textured soil, the 4 dS/m treatment produced significantly higher ratio than that produced at 8 dS/m and 12 dS/m. There were no differences between 0, 8 and 12 dS/m in the loam texture.

The flood*texture interaction is one where sand produced a significantly greater root to shoot ratio than both loam and clay soils, the latter of which were not significantly different (Figure 3.14). In general, the root to shoot ratio declined as flood duration increased for the sand texture, where there was no significant difference between 0 and 1 week of flooding, but 2 weeks was significantly less than both, 0 and 1 week, and 4 weeks was significantly less than 2 weeks. In the loam, flooding at 4 weeks produced a significantly lower root to shoot ratio than all other treatments, which were not significantly different from each other. Root to shoot ratios for 0, 1 and 2 weeks of

flooding were not significantly different in the clay soil, but all of these produced a significantly higher root to shoot ratio than 4 weeks of flooding.

The salt*species*texture interaction is one where both species in sand produced a greater root to shoot ratio than in both loam and clay, except for the 8 dS/m, where Tall Fescue did not produce a different ratio in sand than in clay soil (Figure 3.15). Root to shoot ratios in the loam and clay soils were not significantly different in any of the treatments. Tall Fescue produced a greater root to shoot ratio than Alkali Grass when comparing between the same growth medium over all salt levels, except the 8 dS/m level, where there were no significant differences between Alkali Grass and Tall Fescue in the sand.

The flood*species*texture interaction is one where sand had a higher root to shoot ratio than all others except in Alkali Grass at 4 weeks of flooding where there was no difference between sand, loam and clay (Figure 3.16). Tall Fescue had a higher root to shoot ratio than Alkali Grass at each texture*salt treatment.

The salt*texture*flood interaction shows a general trend of decreasing root to shoot ratios as flood durations increased (Figure 3.17). Sand produced a higher root to shoot ratio than both loam and clay at all treatments.

The four way interaction between species*salt*flood*texture was significant for the root to shoot ratio, which means that the root to shoot ratio for at least one species was significantly affected by the interaction of salt, flooding and texture together. This is a very complicated relationship to illustrate and interpret, so the results are presented in Table A-5 in the appendix rather than in graphs.

Table 3.7: Analysis of Variance for Root to Shoot Ratio.

Sources of Variation	D.F.	F Value	Pr>F
Block	2	0.78	0.4663
Salt	3	9.35	0.0002
Flood	3	15.43	<0.0001
Species	1	562.73	<0.0001
Texture	2	315.35	<0.0001
Error = Block*Salt*Flood	30	5.10	<0.0001
Flood*Species	3	0.23	0.8746
Salt*Species	3	5.14	0.0016
Flood*Texture	6	15.53	<0.0001
Salt*Texture	6	8.91	<0.0001
Texture*Species	2	2.33	0.0981
Salt*Flood*Species	9	1.91	0.0464
Salt*Texture*Species	6	4.42	0.0002
Salt*Flood*Texture	18	1.92	0.0117
Flood*Texture*Species	6	2.91	0.0082
Salt*Flood*Texture*Species	18	3.01	<0.0001

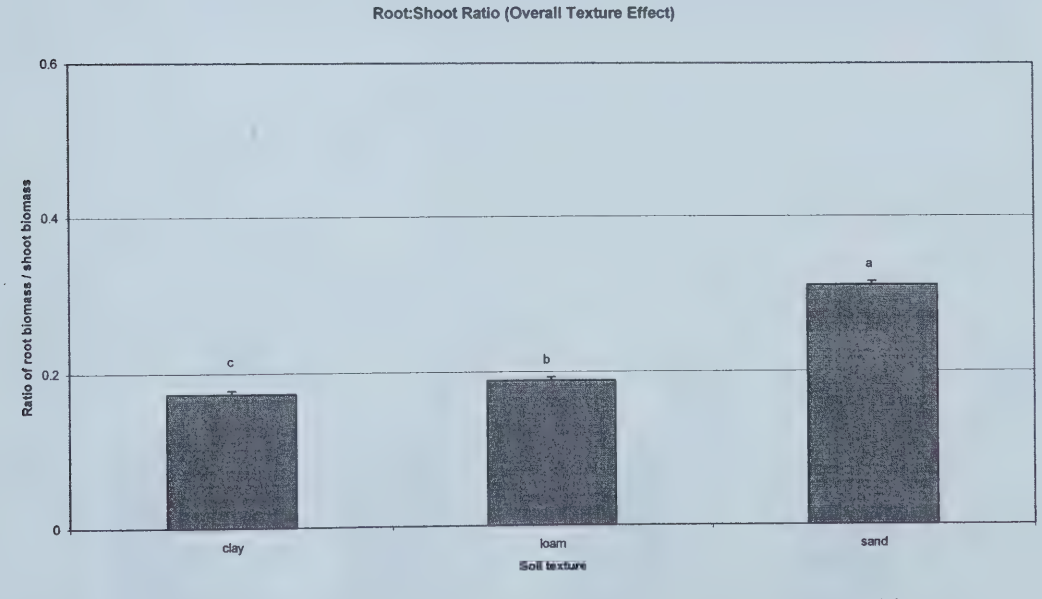

Figure 3.12: Average (LS means) overall root to shoot ratio for each soil texture (shoot biomass/average root biomass for each treatment). Bars include both species at all salt*flood levels. Treatments with common letters are not significantly different (α =0.05).

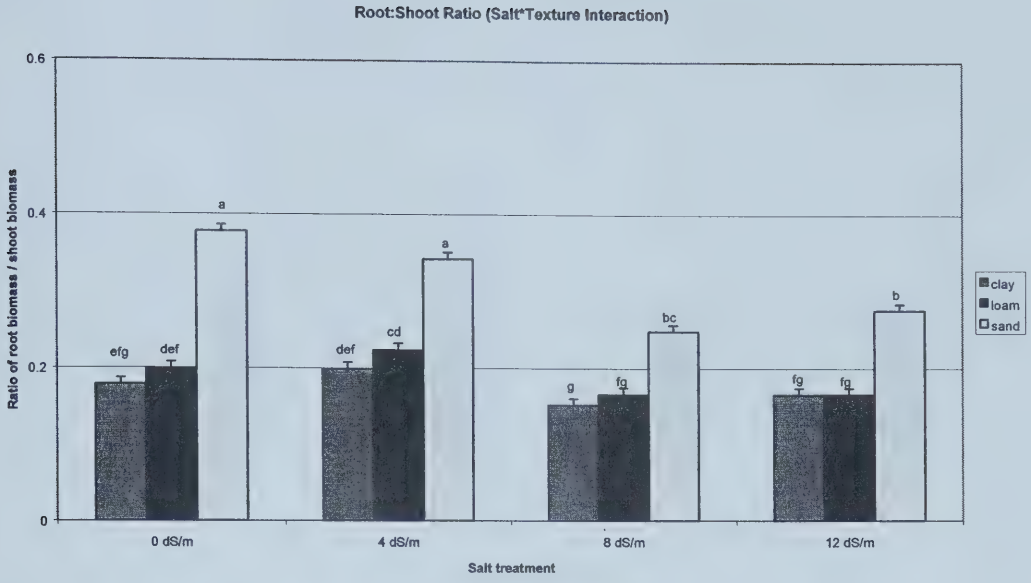

Figure 3.13: Average (LS means) overall root to shoot ratio for each soil texture at each salt treatment (shoot biomass/average root biomass for each treatment). Bars include both species at all flood levels. Treatments with common letters are not significantly different (α =0.05).

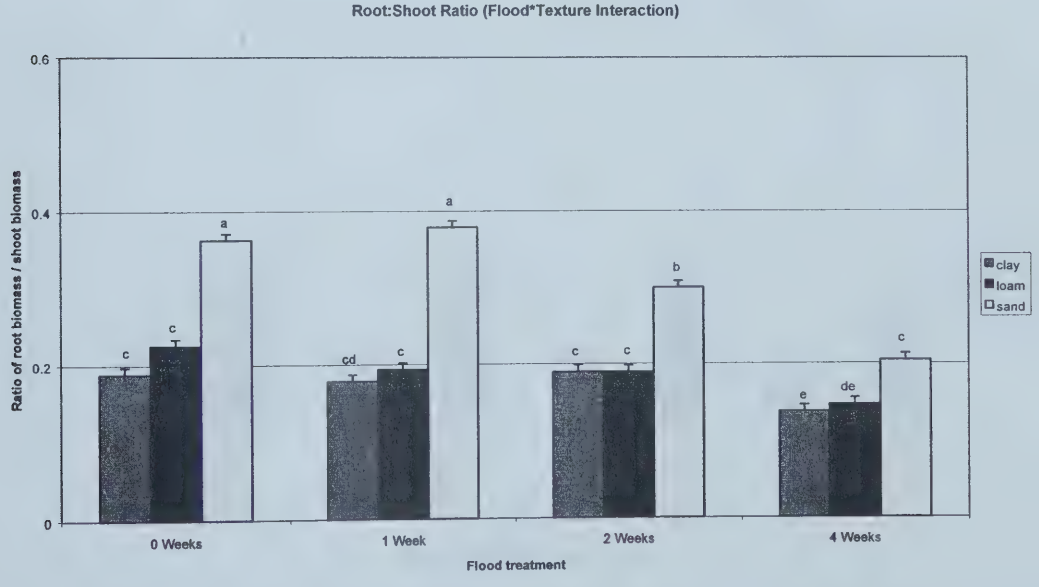

Figure 3.14: Average (LS means) overall root to shoot ratio for each soil texture at each flood treatment (shoot biomass/average root biomass for each treatment). Bars include both species at all salt levels. Treatments with common letters are not significantly different (α =0.05).

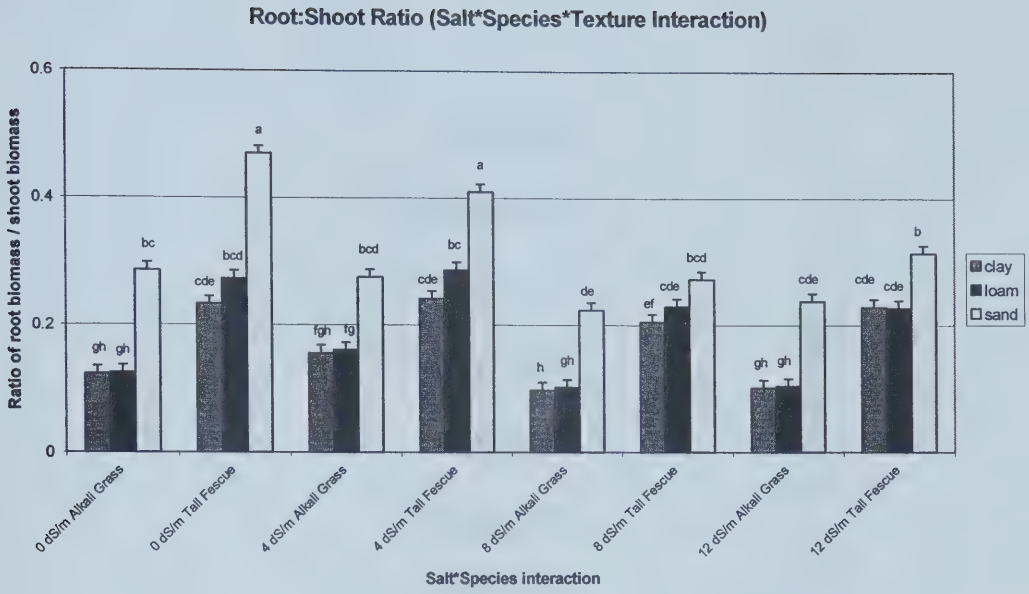

Figure 3.15: Average (LS means) overall root to shoot ratio for each soil texture by each species under all salt treatment (shoot biomass/average root biomass for each treatment). Bars include all salt levels. Treatments with common letters are not significantly different (α =0.05).

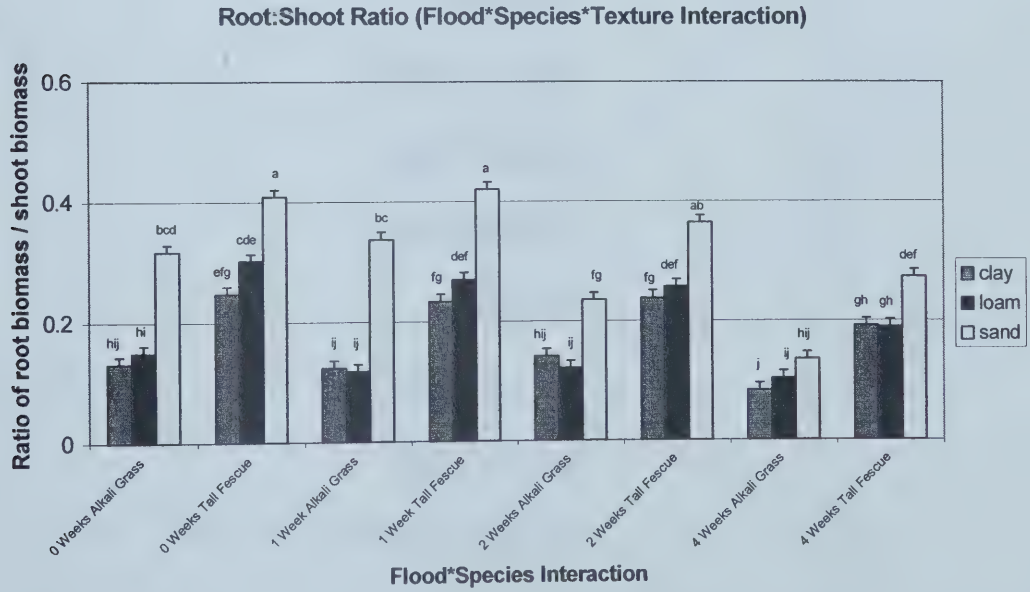

Figure 3.16: Average (LS means) overall root to shoot ratio for each soil texture by each species under all flood treatment (shoot biomass/average root biomass for each treatment). Bars include all flood levels. Treatments with common letters are not significantly different (α =0.05).

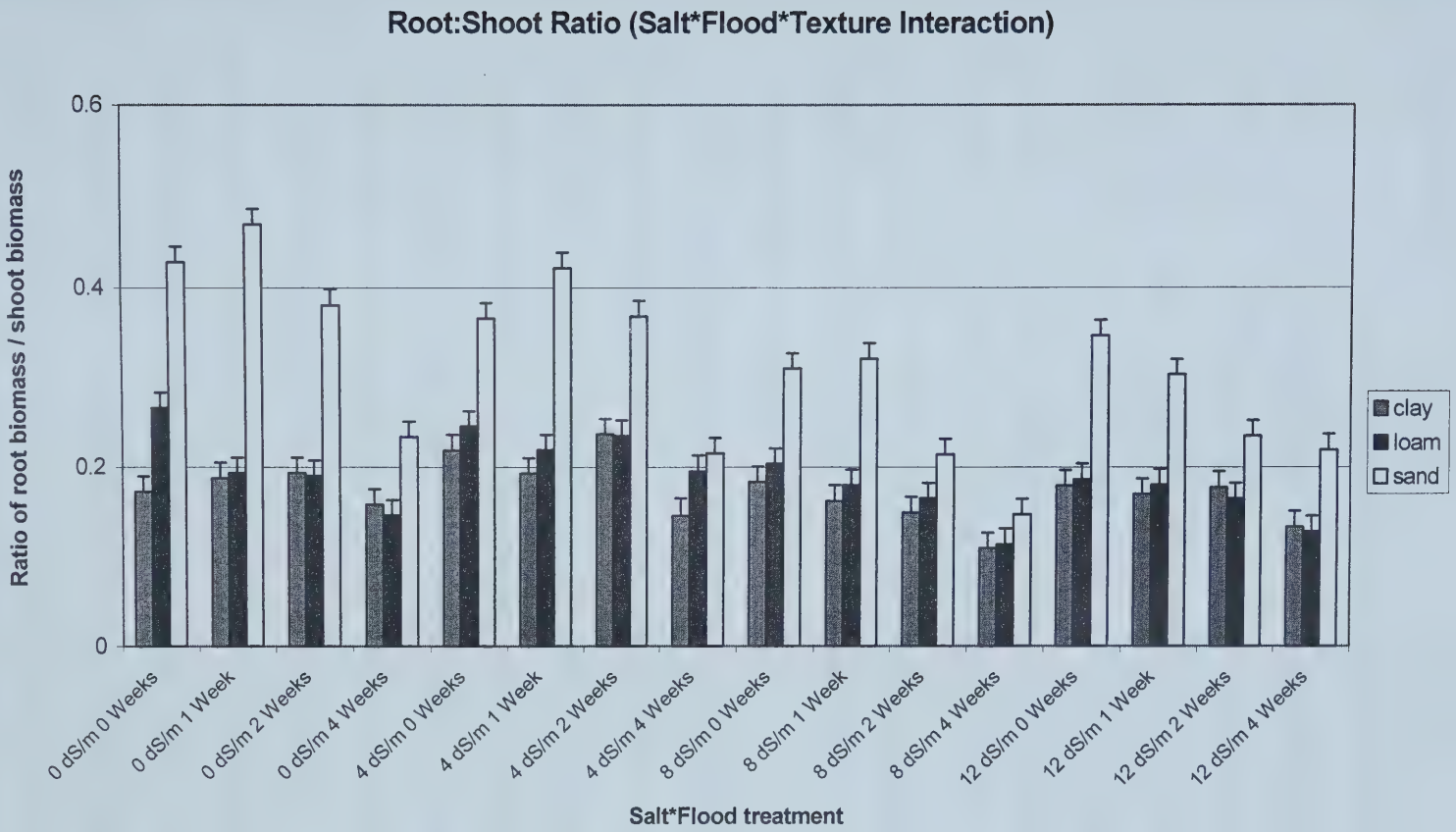

Figure 3.17: Average (LS means) overall root to shoot ratio for each soil texture under all salt*flood treatment (shoot biomass/average root biomass for each treatment). Bars include both species. Treatments with common letters are not significantly different (α =0.05).

3.3 Discussion

In this experiment, as in chapter 2, increased flooding durations of up to four weeks increased above ground biomass production, regardless of soil texture. The amount of below ground biomass produced was maximized at 2 weeks of flooding for the clay and loam textures, and at 1 week of flooding for the sand. While the results for sand were not unexpected because of similar results in chapter 2, it was surprising that the growth in both the clay and loam soils increased with longer flooding durations. It was thought that the soils with a greater percentage of smaller particle sizes (silt and clay sized) would be more deleteriously affected by waterlogged conditions because of smaller pore size and slower exchange of gases between the soil and water and/or atmosphere interface (Hausenbuiller, 1985).

One explanation for the lack of negative impact of waterlogged conditions on plant growth may have been soil aggregation. As mentioned in the introduction, soils with finer particle sizes tend to form aggregates. Aggregate structure influences soil properties such as: aeration, infiltration, drainage, bulk density, and resistance to erosion (Gale et al., 2000). If the aggregates were stable in water and of sufficient size in the clay and loam soils, this may have allowed for more rapid resumption of aeration after the flooding treatments were finished and continual solution movement through the growth medium during flooding, just as was hypothesized for the sand in chapter 2. Sand had large pores due to large particle size, where as the clay and loam soils may have had large inter-aggregate (between aggregates) pores due to aggregation, allowing for a similar effect. As in chapter 2, the nutrient solution may not have been devoid of oxygen, and any solution movement through the growth media could have delivered oxygen to the

roots; bubbling N_2 gas into the solution would have artificially removed the oxygen from the solutions, thus ensuring anoxic conditions (Huang et al., 1994).

The overall increase in biomass in all soil textures with increased durations of flooding may be explained primarily by the fact that plants subjected to longer flooding durations were also continually exposed to the nutrients in the Hoagland's solution for the duration of the flooding treatment, where as the non-flooded plants were not continually exposed to the nutrients, but were instead watered regularly with the solution. Another reason for increased growth with the increased flooding could be the fact that the species tested in this experiment are known to be somewhat flood tolerant, and are often found growing in moist sites (Hardy BBT Limited, 1989). Alkali Grass is often found growing in moist to wet saline areas; Tall Fescue is reported to prefer moist sites and dies out under drier conditions (Hardy BBT Limited, 1989).

Many flood tolerant plant species have adaptive morphological-anatomical mechanisms, such as aerenchyma, that allow them to tolerate waterlogged conditions (Krizek, 1982; Huang et al., 1994; Colmer, 2003; Visser et al., 2003). An aerenchyma is an intercellular air-filled space or channel that provides a lower resistance internal pathway for gas diffusion (Drew, 1997; Colmer, 2003). Aerenchyma formation in flood tolerant and aquatic species generally occurs as cell separation during development (schizogeny), whereas they are generally formed after cell death and dissolution (lysigeny) in other, less well-adapted plants (Drew, 1997). Aerenchyma formation in roots of plants is fairly widespread, even among dry-land vegetation (Drew, 1997). Perhaps Alkali Grass and Tall Fescue have similar adaptations that allow for the degree of flood

tolerance exhibited in this experiment. Unfortunately, root tissue samples were not examined for the development of aerenchyma in this experiment.

While the stimulatory effect of increased flooding on the production of shoot biomass is unusual when exploring the bulk of the literature, it is by no means unheard of. Experiments involving wheat (Trought and Drew, 1980; Barrett-Lennard et al., 1988; Huang et al., 1994) have shown that the above ground biomass of some genotypes of different plant species is not affected by, and in some cases is actually stimulated by waterlogged conditions. Huang et al. (1994) found that after 14 days of flooding, only 2 of 6 wheat genotypes tested exhibited a significant decrease in shoot biomass, and after 21 days of flooding, 1 of the 6 still produced similar amounts of above ground biomass to that of the aerated controls. In the experiment by Barrett-Lennard et al. (1988), hypoxia for 14 days did not have a significant effect on shoot production, whereas Trought and Drew (1980) actually found an increase in above ground biomass after 8 days of anoxic conditions.

Plants grown in the clay textured soil produced the greatest amount of above ground and below ground biomass, regardless of the flood duration or salt treatment. Sand had the lowest above ground biomass in all treatments, but either produced significantly more below ground biomass or similar amounts than the loam textured soil. The increased shoot growth in clay and loam soils may be due to the increased amounts of nutrients and organic matter in the soil initially when compared to the sand (Table 3.1), or because of the differences in pH. In almost all cases the clay soil had greater initial nutrient content than the loam soil, which had greater initial nutrient content than the sand. Because of imperfect experimental control (unequal baseline fertility for the different

growth media) it is difficult to suggest the reason for the enhanced shoot and root growth of the plants grown in clay over those grown in loam and sand, and the plants grown in loam over those grown in sand, as it could be due to the increased initial fertility, or some texture-related mitigating factor to tolerating salinity and flooding. Even though plants grown in sand had lower shoot and root biomass than those grown in clay and loam soils, the root to shoot ratios shown in the results section show the opposite trend, where plants grown in sand have the greatest ratio, followed by plants in the loam and clay textured soils (very few significant differences in root to shoot ratios were detected between the clay and loam soils). This suggests that there was increased preferential partitioning of carbon to the above ground biomass for the clay and loam soils when compared to the sand. The lower root to shoot ratio in the clay and loam soils may be due to a slight aversion to the growth media because of decreased gas diffusivity (possibly leading to oxygen deprivation) and increased resistance to rooting because of smaller pore size. Root to shoot ratios are generally lower under oxygen deprived conditions than under aerated conditions (Glińsky and Stępniewski, 1985). According to Hausenbuiller (1985) and Naeth et al. (1991), root growth is often inhibited in soils with decreased porosity, largely due to decreased aeration. This effect was also illustrated in the texture*flood interaction, where the root to shoot ratios were significantly reduced under the four week flood duration for all soil textures when compared to the 0, 1 and 2 week durations. Another factor potentially impacting the root to shoot ratios was the ease of washing (and therefore capturing) roots from plants grown in sand compared to those in the clay and loam soils.

3.5 Conclusions

This experiment was able to meet the objectives of determining if coarse soil texture was the reason for the increased plant growth with increased flooding detected in chapter 2, as well as to find out if plant growth in soil was similar to that in sand.

This experiment yielded results similar to the experiment in chapter 2 (plant performance in sand was similar to performance in soil), where increased levels of salt suppressed growth and where increased flooding durations increased growth. The hypothesis that the clay and loam soils would be more negatively affected by increased durations of flooding was rejected. Both above ground and below ground biomasses were greater in the clay and loam soils than in the sand, again, where increased flooding actually increased the amount of biomass produced. However, the lower root to shoot ratios in clay and loam soils, as well as the decreased R:S ratios with increased flooding in all soils, indicate a preferential partitioning to above ground biomass possibly due to an inhibition of root growth with reduced aeration.

The use of three different growth media made for challenges not encountered when using sand alone. Possible confounding effects due to differences in baseline levels of nutrients as well as organic matter and pH, made the effect of texture on root and shoot growth difficult to discern.

3.6 References

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4. Testing the Ability of Selected Species to Grow in Soil Collected From a Wetland-Cropland Ecotone

4.1 Introduction

It was proposed earlier that by implementing vegetated buffer strips comprised of numerous plant species, each selected for ability to tolerate a range of salinity and flooding within saline wetland-cropland ecotones, that the wetland would be better protected from some of the impacts of agriculture. It was also thought that the degree of salinization might be reduced over the long term, while the plants could be harvested to provide a reliable source of forage.

While many of the experiments selecting for plant salt tolerance cited in the literature use either sand or water culture (Ashby and Beadle, 1957; Phleger, 1971; Venables and Wilkins, 1978; Dalton et al., 2000; Hamilton et al., 2001), there has been very little if any effort to find out if the results correlate to actual field conditions. Venables and Wilkins (1978) postulated that salt may be more toxic in culture solution than in soil, as salt toxicity in soil may be reduced by adsorption onto colloids or because of increased buffering. Although, according to Ashraf et al. (1986), salt tolerance can be selected for in solution culture. Because of the lack of information on the correlation of sand and water culture conditions to actual field conditions, a major objective of this experiment, as an intermediate step towards field implementation, was to determine if plant performance in artificially salinized sand was a good predictor of performance in naturally salinized soil collected from a wetland-cropland ecotone.

In the previous chapters, plants were tested for ability to grow in saline media of up to 12 dS/m. While the electrical conductivities tested (0, 4, 8 and 12 dS/m) offered

reasonable coverage of the range from non-saline to strongly saline (Wentz, 2003a), soil conditions in very saline areas may be upwards of 20 dS/m (Greenlee et al., 1968). While a major goal when dealing with saline soils is to prevent exacerbation to this level by adopting cropping practices that reduce accumulation of excess moisture in the upper slope areas (Ballantyne, 1963) such as increasing minimum or no-tillage operations, increasing production of forages and/or including salt-tolerant crops in rotations (Eilers et al., 2000), areas exist where soil salinity is so high as to inhibit all plant growth. In order to test the upper tolerance limits of the plant species used in chapter 2, the 11 plant species were grown in soil collected from distinct zones within a saline wetland-cropland ecotone. The soil and vegetation conditions ranged from not visibly saline, with the vegetation present offering good ground cover, to where plant growth was severely inhibited and salts were visible at the soil surface. In chapter 2, the 11 species were tested in two separate trials of 6 and 5 species respectively, and while similar in setup and execution, direct comparisons between the two trials could not be made. In this trial, because all species were used at the same time under the same conditions, direct comparison could be made between all 11 species.

It was hypothesized that plant performance in the soil collected from the ecotone would show trends similar to those seen in chapter 2 (plants were grown in artificially salinized sand), where increased salinity would decrease shoot growth and survival, and where some species would prove to be more salt tolerant than others. It was also expected that Tall Fescue and Alkali Grass, the most salt tolerant species tested in chapter 2, would be the most likely to survive and produce biomass in the most saline soil collected from the ecotone. Conversely, the least salt tolerant species from chapter 2,

Timothy and Tufted Hair Grass, were not expected to survive at the greatest levels of salinity. Based on the results from the previous 2 chapters, it was expected that flooding would not have a negative impact on plant growth, but would instead have a stimulatory effect on growth.

4.2 Methods

4.2.1 Growth Media Preparation

Soil was collected in October 2002 from the surface 20 cm of four distinct zones, demarcated by changes in vegetation, along a transect through a salt affected wetland-cropland ecotone in a field near Mundare, Alberta (approximately 53° 34′ N, 112° 34′ W). The soil from each zone was thoroughly homogenized in a soil mixer and was then autoclaved to kill any weeds. Soil chemical and physical properties for the soil collected from each zone (surface 15 cm), as analyzed by Norwest Labs (9938-67 Avenue Edmonton, Alberta, Canada) are presented in Table 4.1. Dominant vegetation, width, soil horizons, EC and pH of each of the 4 zones within the ecotone are presented in Table 4.2.

The soil was not sieved as in previous experiments so as not to further disturb soil aggregates. Stable aggregate size class distribution assessments for the soil from each zone were done by wet sieving slaked (air dried soil rapidly immersed in water) representative composite samples for each soil zone (adapted from Elliott, 1986; Gale et al., 2000; Six et al., 2000). The results of the aggregate size class distributions are presented in Table 4.3.

The soils were then placed in garden boxes with dimensions 56 cm long x 17 cm wide x 12 cm deep and a volume of 0.0114 m^3. There were 12 garden boxes for each soil

zone (replicates), with a total of 48 garden boxes (these twelve replicates for each soil zone were further divided into four flooding treatments of 0, 1, 2 and 4 weeks with three replicates each for the zone*flooding combination for the latter half of the experiment). Each garden box contained soil from a single zone, where each zone had a general level of salinity as expressed by electrical conductivity.

Table 4.1: Physical characteristics of the soil used in the trial (collected from the 0-15 cm depth in each zone within the ecotone).

Characteristic	Zone 1 (6 ds/m)	Zone 2 (11 dS/m)	Zone 3 (17 dS/m)	Zone 4 (29 dS/m)
% sand	42.6	47.6	43.2	42.6
% silt	33.3	30.7	33.3	35.3
% clay	24.1	21.7	23.5	22.1
pH	8.4	8.5	8.3	8.2
EC (dS/m)	6.1	11.1	17.0	29.3
Organic matter (%)	4.3	3.7	4.0	3.5
N (Nitrate) (mg/kg)	7.7	2.4	1.1	4.2
P (mg/kg)	31.0	>60.0	>60.0	>60.0
K (mg/kg)	230.0	215.0	186.0	238.0
S (Sulphate) (mg/kg)	>20.0	>20.0	>20.0	>20.0
Ca (mg/kg)	4400.0	3860.0	3440.0	1920.0
Mg (mg/kg)	1280.0	1340.0	1560.0	3070.0
Fe (mg/kg)	115.0	79.0	49.0	38.0
Cu (mg/kg)	2.2	1.5	1.1	1.0
Zn (mg/kg)	4.0	3.5	4.7	4.6
B (mg/kg)	1.5	1.6	1.4	1.9
Mn (mg/kg)	36.2	25.2	20.8	38.5
Cl (mg/kg)	61.6	30.3	13.5	11.4

Table 4.2: Characteristics of the ecotone including: dominant vegetation, width of each zone, soil horizons, depth of horizon EC and pH.

Zone	Dominant Vegetation	Width of Zone (m)	Soil Horizons	Depth (cm)	EC (dS/m)	pH
Zone 1 (6 ds/m)	Slim Stem Reed Grass (*Calamagrostis stricta*), Northern Wheatgrass (*Agropyron dasystachum*), Silver Weed (*Potentilla anserina*)	6.8	Ahk	0-18	6.06	8.67
			Bmkgj	18-30	4.31	8.04
			I Ckgj	30-50	3.82	8.29
			II Ckg	50-80	4.65	7.75
Zone 2 (11 dS/m)	Foxtail Barley (*Hordeum jubatum*), Alkali Grass (*Puccinellia nuttaliana*), Tufted White Prairie Aster (*Aster ericoides*), Silver Weed (*Potentilla anserina*)	6.4	Ahks	0-22	11.01	8.65
			Bmkgj	22-44	7.39	7.38
			Ckgj	44-120	3.56	8.64
Zone 3 (17 dS/m)	Alkali Grass (*Puccinellia nuttaliana*), Foxtail Barley (*Hordeum jubatum*), Sea Blite (*Suaeda calceoliformis*)	6.2	Ahks	0-21	17.02	8.37
			Bmk	21-31	7.81	8.43
			Ckgj1	31-44	5.65	7.98
			Ckgj2	44-75	7.53	7.88
Zone 4 (29 dS/m)	Sea blite (*Suaeda calceoliformis*)	4.2	Ahs	0-16	29.32	8.17
			Ahks	16-27	10.31	7.76
			AC(ks)	27-34	13.76	8.31
			Cks	34-70	11.79	8.32
			Ckgjs	70-100	not sampled	not sampled

Table 4.3: Percent of soil falling within each aggregate size class for each of the 4 zones within the ecotone after wet sieving.

	% of soil falling within each size class for 4 zones within the ecotone			
Aggregate Size Class	Zone 1	Zone 2	Zone 3	Zone 4
> 6300 μm	3.3	9.9	8.8	6.0
4000 μm to 6300 μm	1.6	1.8	2.1	1.7
2000 μm to 4000 μm	3.0	1.2	1.1	1.0
1000 μm to 2000 μm	3.6	3.1	1.9	2.7
500 μm to 1000 μm	19.1	20.4	7.9	14.6
<500 μm	69.6	63.5	79.1	74.0

4.2.2 Experimental Design

The experiment was set up as a split plot in a growth chamber with an approximate temperature range of 15° C night and 22° C day and a 16-hour photoperiod. Garden boxes containing soil from each zone (further divided into zone*flooding treatments after plant establishment) were considered as part of the whole plot. Plant species were considered as the sub-plot.

The 11 species used in this experiment, previously determined to have germination rates of at least 20% under saline conditions up to 12 dS/m, were as follows: Crested Wheatgrass (*Agropyron pectiniforme* R. & S.), Alkali Grass (*Puccinellia nuttalliana* (Schulte.) A.S. Hitchc.), Russian Wild Rye (*Psathyrostachys juncea* Fisch.), Reed Canary Grass (*Phalaris arundinacea* L.), Redtop (*Agrostis stolonifera* L.), Tufted Hair Grass (*Deschampsia cespitosa* (L.) Beauv.), Creeping Red Fescue (*Festuca rubra* L.), Timothy (*Phleum pretense* L.), Tall Fescue (*Festuca arundinacea* Schreb.), Bird's-foot Trefoil (*Lotus corniculatus* L.) and Alfalfa (*Medicago sativa* L.).

In order to establish the plants under saline conditions from 6 up to 29 dS/m, the plants were grown in the saline soil without flooding for 2 months. Fifteen seeds of each

of the 11 species were planted into all garden boxes in 11 rows. Each row contained a single species; the species planted in each row were randomized so that each species had a random chance of being located beside another in each garden box. Garden boxes were randomly placed in 3 blocks along the growth chamber bench. Each of the garden boxes was initially watered with 2.5 cm of water, and after that the soil was kept moist, but was not watered so heavily as to cause leaching of salts out the bottom of the boxes. The garden boxes were uniformly watered when soil began to dry out (approximately 3 times per week). A tray was kept under each box to ensure that if leaching occurred, water containing potentially leached salts could be placed back into the box. After seedling emergence, the seedlings were thinned to 3 plants per row (3 plants per species per garden box for a maximum total of 9 plants for each Zone*Flood treatment, and 144 plants of each species overall).

After two months of plant establishment, the flooding component of the trial was started. As in chapter 3, the plants in this experiment were not placed in the coldroom to induce a dormant-like state in order to prevent extraneous plant death not associated with salinity. The flooding treatments included a control of 0 weeks, as well as durations of 1, 2 and 4 weeks. The non-flooded treatments (controls) were uniformly watered when soil began to dry out (approximately 3 times per week). Holes at the bottom of each garden box to be flooded were plugged, and the soil was saturated up to the soil surface (without free water above the surface). Water was added as needed to the flooded treatments in order to maintain conditions of saturation up to the soil surface (St. Omer and Schlesinger, 1980). After each flooding treatment was complete, the holes were unplugged, and the

leachate collected. Leachate was then used to water the plants over the remaining duration of the experiment to minimize salt loss and subsequent change in EC.

After all flooding durations were completed, the number of surviving plants of each species were counted. The shoots of all plants were harvested at the soil surface and bagged separately. The shoot samples were dried at 65° C until biomass reached a constant weight (approximately 48 hours); biomass was measured and recorded. The roots from each of the species could not be separated, so unlike the previous chapters, root biomass was not determined. As a result, species performance was based on survival and above ground biomass.

4.2.3 Statistical Analyses

This experiment was set up as a three-factor factorial, split plot design, with block and the zone*flooding treatments considered as the main plot. The three factors were zone, flood and species; zone had 4 levels (electrical conductivities of approximately 6, 11, 17 and 29 dS/m), flood had 4 levels (0, 1, 2 and 4 week durations) and species had 11 levels. Block, salt and flood effects (whole plot) were tested with the interaction (block*zone*flood) as the error term. All other effects and interactions (sub-plot) were tested with the natural error term. Probabilities and F-values reported for species and salt are the type III, calculated using the specified error term. Means, LS means, standard errors and ANOVA were calculated using GLM (general linear model), and the Chi-Squared maximum likelihood analysis of variance was calculated using CATMOD (categorical model), in the SAS 8.0 statistical package (1999-2000). Normality was tested using the Shapiro-Wilks test within UNIVARIATE (SAS, 1999-2000). Post-hoc

multiple comparisons of significant response variables and interactions were completed using the Tukey-Kramer adjusted pairwise comparisons of the LS means. Treatment, species and interaction effects were considered significant at α=0.05. Species, zone and flood were completely crossed, fixed effects.

4.3 Results

4.3.1 Survival

Survival rates of all species dropped markedly from zone 1 (6 dS/m) to zone 4 (29 dS/m) (Table 4.5). This follows the same trend as in chapter 2, where increasing levels of salinity had a negative effect on the survival of the plants. Of the 11 species tested, only Alkali Grass, Tall Fescue, Russian Wild Rye and Crested Wheatgrass had any surviving plants in zone 4 (29 dS/m), Crested Wheatgrass with only 1 out of 36 plants surviving. As in chapter 2, both Alkali Grass and Tall Fescue had the greatest rates of overall survival, Alkali Grass with almost 87% survival and Tall Fescue with just over 77%. While these overall rates are lower than in chapter 2 they are likely due to the higher levels of salinity tested in the current experiment than in chapter 2. Timothy, Redtop and Tufted Hair Grass had the lowest levels of survival overall. Both Timothy and Tufted Hair Grass had the lowest levels of survival in chapter 2. The lower survival rates of Redtop in this experiment were a bit surprising, as Redtop had the second greatest rate of survival in chapter 2 (trial 1). At the 17 dS/m level (zone 3), 6 of the 11 species had survival rates over 30% (Alkali Grass, Tall Fescue, Russian Wild Rye, Crested Wheatgrass, Reed Canary Grass and Creeping Red Fescue). The remaining species (Bird's-foot Trefoil, Alfalfa, Timothy, Redtop and Tufted Hair Grass) all had less than

14% survival at the 17 dS/m level, and because of inadequate replication due to plant death/inability to germinate, could not be analyzed for above ground biomass at this EC level.

While the effect of flood treatment on survival was significant, there was no clear trend. Both flood 1 (0 weeks) and flood 3 (2 weeks) had the greater rates of survival. The survival rates of flood 2 (1 week) and 4 (4 weeks) were lower, flood 4 had the lowest survival rate overall (Table 4.6).

Table 4.4: Maximum likelihood Analysis of Variance for survival.

Sources of Variation	D.F.	Chi-Square	Pr>Chi Square
Species	10	202.79	<0.0001
Zone	3	338.15	<0.0001
Flood	3	7.84	0.0495
Species*Zone	30	106.65	<0.0001
Species*Flood	30	35.61	0.2210
Species*Zone*Flood	90	60.46	0.9929

Table 4.5: Number of plants survived, survival percentages and totals for all species in all zones.

Species	Zone 1 (6 dS/m)		Zone 2 (11 dS/m)		Zone 3 (17 dS/m)		Zone 4 (29 dS/m)		**Total**	
	#	%	#	%	#	%	#	%	#	%
Alkali Grass	36	100.0	36	100.0	36	100.0	17	47.2	**125**	**86.8**
Tall Fescue	36	100.0	36	100.0	32	88.9	7	19.4	**111**	**77.1**
Russian Wild Rye	34	94.4	36	100.0	32	88.9	8	22.2	**110**	**76.4**
Reed Canary Grass	33	91.7	30	83.3	17	47.2	0	0.0	**80**	**55.6**
Creeping Red Fescue	35	97.2	31	86.1	11	30.6	0	0.0	**77**	**53.5**
Bird's-foot Trefoil	31	86.1	33	91.7	5	13.9	0	0.0	**69**	**47.9**
Alfalfa	34	94.4	27	75.0	4	11.1	0	0.0	**65**	**45.1**
Crested Wheatgrass	20	55.6	21	58.3	20	55.6	1	2.7	**62**	**43.1**
Redtop	28	77.8	27	75.0	2	5.6	0	0.0	**57**	**39.6**
Timothy	17	47.2	23	63.9	4	11.1	0	0.0	**44**	**30.6**
Tufted Hair Grass	23	63.9	16	44.4	2	5.6	0	0.00	**41**	**41.0**
Total	**327**	**82.6**	**316**	**79.8**	**165**	**41.7**	**33**	**8.3**	**841**	**53.1**

Table 4.6: Number of plants survived, survival percentages and totals for all flood levels.

Flood 1 (0 Weeks)		Flood 2 (1 Week)		Flood 3 (2 Weeks)		Flood 4 (4 Weeks)		**Total**	
#	%	#	%	#	%	#	%	#	%
218	55.1	202	51.1	221	55.8	200	50.5	**841**	**53.1**

4.3.2 Above Ground Biomass

Due to the deleterious nature of the soil collected from both zone 3 (17 dS/m) and zone 4 (29 dS/m) it is not surprising to see the low levels of survival of most species in these zones. Because of the large amount of missing data due to plant death and/or failure to germinate, it was not possible to analyze the above ground biomass data for all species in all soil zones. There was sufficient survival and replication to analyze the above ground biomass for all 11 species in both zone 1 (6 dS/m) and zone 2 (11 dS/m), but not zone 3 or zone 4. However, 6 of the 11 species had sufficient survival and replication to analyze above ground biomass data from zones 1, 2 and 3, but not zone 4. Consequently, results for above ground biomass are presented in two sections, the first for all 11 species in zone 1 and zone 2 soils, and the second for 6 of the 11 species (Tall Fescue, Alkali Grass, Russian Wild Rye, Reed Canary Grass, Crested Wheatgrass and Creeping Red Fescue) in zones 1, 2 and 3.

4.3.2.1 All Species in Zone 1 and 2

The effect of zone shows that the amount of above ground biomass produced in zone 1 was significantly greater than in zone 2 (Figure 4.1). This is a similar relationship

to that reported in chapter 2, where increasing levels of salt decrease the total amount of above ground biomass produced.

The effect of species on the amount of above ground biomass produced shows that Tall Fescue and Alkali Grass produced significantly more biomass than all other species; Tall Fescue produced significantly more than Alkali Grass (Figure 4.2). Reed Canary Grass produced significantly more biomass than Redtop, Bird's-foot Trefoil, Alfalfa, Timothy and Creeping Red Fescue, but not Russian Wild Rye. Tufted Hair Grass or Crested Wheatgrass. There were no significant differences in the amount of above ground biomass produced between Redtop, Bird's-foot Trefoil, Alfalfa, Timothy, Creeping Red Fescue, Russian Wild Rye or Crested Wheatgrass. In Chapter 2 (trial 2), Tall Fescue produced significantly more above ground biomass than the other species tested, but in trial 1, there was very little differentiation between all species, with only Russian Wild Rye producing significantly less biomass than all other species.

The zone*species interaction is one where only Alkali Grass and Tall Fescue produced significantly less biomass at 11 dS/m (zone 2) than 6 dS/m (zone 1), there were no significant differences between zone 1 and zone 2 for any of the other species (Figure 4.3). Both Alkali Grass and Tall Fescue still produced significantly more biomass than all other species at the 6 dS/m level; there were no significant differences between all other species at this level. Tall Fescue produced significantly more above ground biomass at 11 dS/m than all other species, except for Alkali Grass, which produced significantly more biomass than all species except Crested Wheatgrass and Reed Canary Grass. Reed Canary Grass produced significantly more biomass than Bird's-Foot Trefoil. There were no significant differences between any of the other species. As in chapter 2,

Tall Fescue and Alkali Grass produced more above ground biomass than the other species at the higher levels of salt.

The species*flood interaction is one where increasing durations of flooding have very little effect on the above ground biomass production for the majority of species tested (Figure 4.4). The amount of above ground biomass produced by Alkali Grass at two weeks of flooding was significantly greater than that produced with no flooding. There were no significant differences between any of the flood durations for the other species. Tall Fescue produced significantly more biomass than all other species except Alkali Grass at 1, 2 and 4 weeks of flooding. There was no significant difference among Alkali Grass, Reed Canary Grass and Tall Fescue at 0 weeks of flooding. Alkali Grass produced significantly more biomass than all other species except Tall Fescue at two weeks of flooding, more than all other species except Tall Fescue, Reed Canary Grass and Crested Wheatgrass at four weeks of flooding, and more than all other species except Tall Fescue, Reed Canary Grass and Tufted Hair Grass at 1 week of flooding. There were no significant differences between any of the other species at all flood durations. As in the previous chapters, flooding did not have a deleterious effect on above ground biomass, but there does not appear to be a significant stimulatory effect of flooding on the above ground biomass of any of the species except Alkali Grass, which as mentioned, was stimulated by 2 weeks of flooding over 0 weeks. The fact that Hoagland's solution was not used in this trial may account for the lack of stimulation with increased flooding.

The 3-way interaction between flood*species*zone was significant and results are shown in Table A-6 in the appendix instead of graphically as this is a complicated relationship to illustrate and interpret.

Table 4.7: Analysis of Variance for above ground biomass production for all 11 species in zones 1 and 2.

Sources of Variation	D.F.	F Value	Pr>F
Species	10	68.40	<0.0001
Zone	1	5.49	0.0344
Flood	3	3.30	0.0518
Species*Zone	10	5.06	<0.0001
Species*Flood	30	1.66	0.0159
Species*Zone*Flood	30	2.46	<0.0001

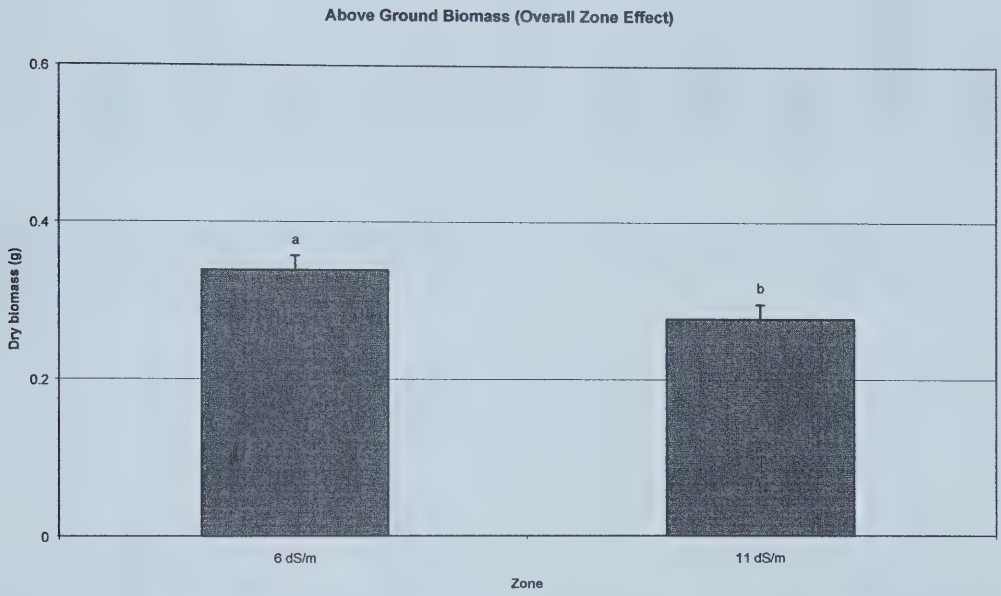

Figure 4.1: Average (LS means) above ground biomass produced per plant in soil zones 1 and 2. Bars include all 11 species in all flooding treatments. Bars with common letters are not significantly different (α =0.05).

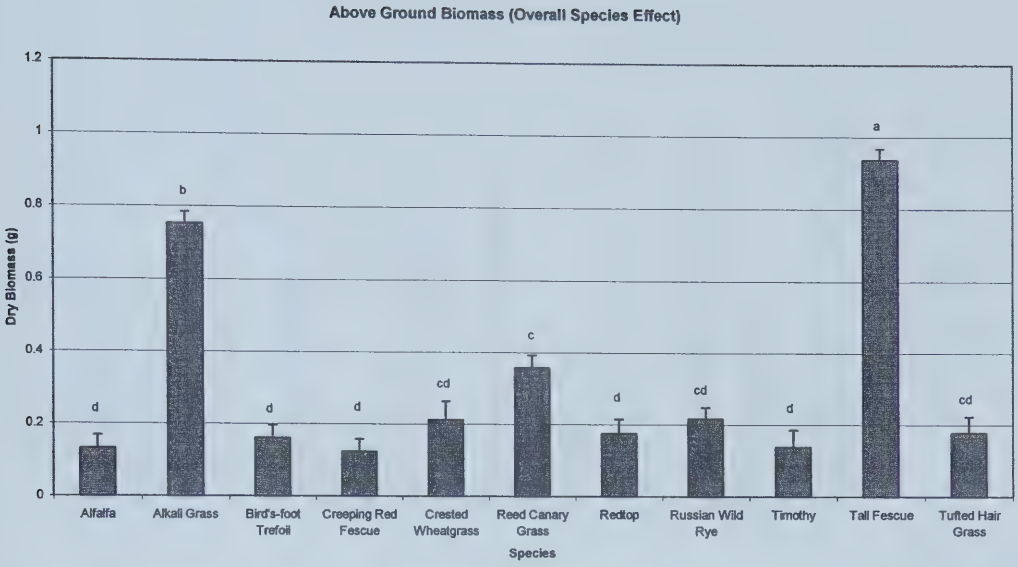

Figure 4.2: Average (LS means) above ground biomass produced per plant by each of the 11 species. Bars include Zone 1 and 2 at all flooding durations. Bars with common letters are not significantly different (α =0.05).

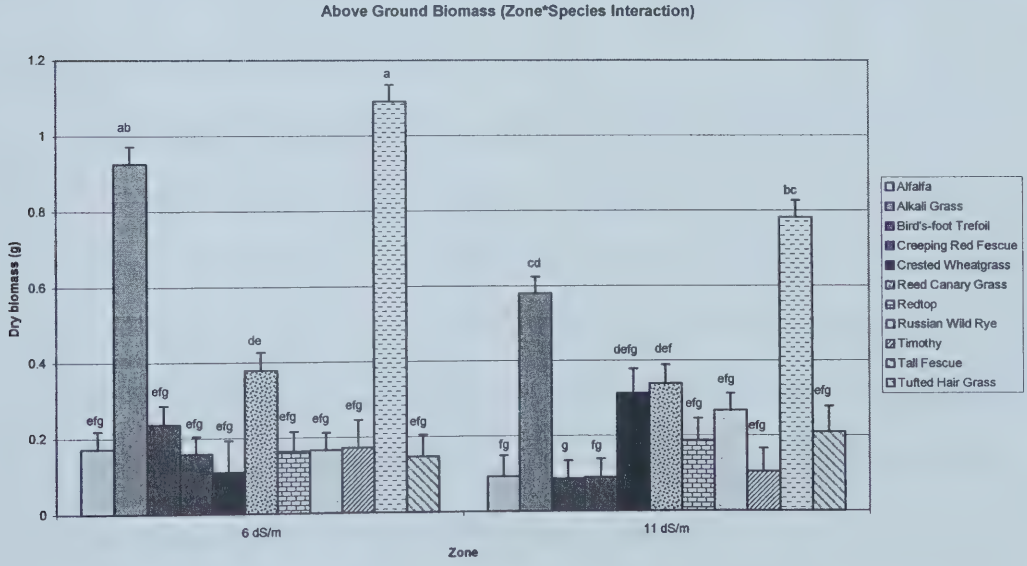

Figure 4.3: Average (LS means) above ground biomass produced per plant in soil zones 1 and 2 by each of the 11 species. Bars include all flooding treatments. Bars with common letters are not significantly different (α =0.05).

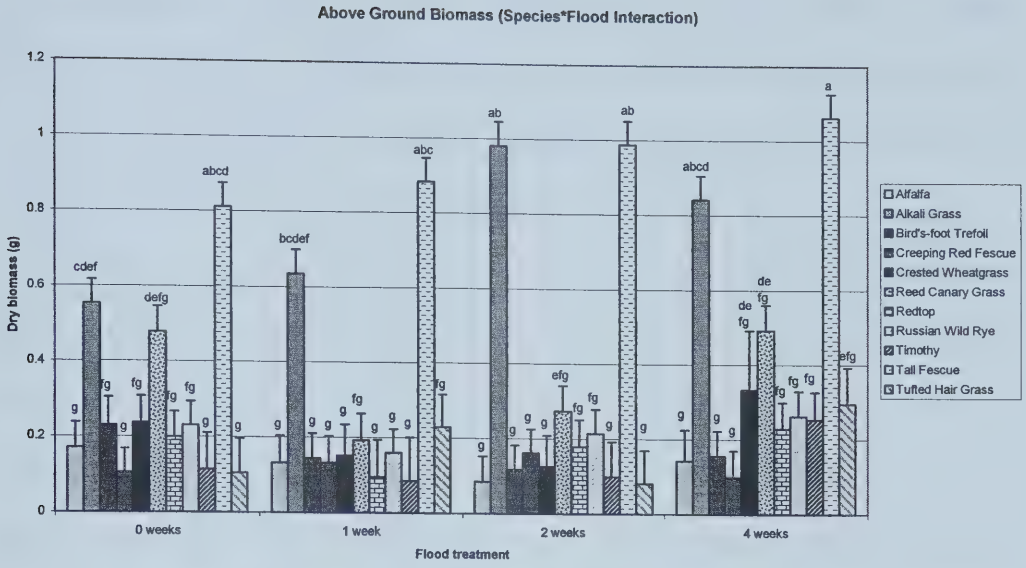

Figure 4.4: Average (LS means) above ground biomass produced per plant under all flooding durations by each of the 11 species. Bars include both soil zones 1 and 2. Bars with common letters are not significantly different (α =0.05).

4.3.2.2 Tall Fescue, Alkali Grass, Russian Wild Rye, Reed Canary Grass, Crested Wheatgrass and Creeping Red Fescue in Zone 3

According to the overall species rankings for salt tolerance as shown in chapter 2 (Tables 2.21 and 2.23), it is not surprising that Timothy (ranked 3rd out of 3), Tufted Hair Grass (ranked 6th out of 6) as well as Alfalfa and Bird's-Foot Trefoil (not included due to very poor survival) were the species that were excluded from the analysis at 17 dS/m. It was surprising, however, that Redtop (previously ranked as the 2nd most salt tolerant out of 6) had such poor survival at the 17 dS/m level as to be excluded. The threshold for survival for Redtop is likely between 12 dS/m and 17 dS/m.

The effect of species on the amount of above ground biomass produced shows that Tall Fescue produced significantly more than Alkali Grass, which produced significantly more biomass than the other species (Reed Canary Grass, Crested

Wheatgrass, Russian Wild Rye, Creeping Red Fescue) (Figure 4.5). Reed Canary Grass produced significantly more biomass than Creeping Red Fescue, but not Russian Wild Rye or Crested Wheatgrass. There were no significant differences between Creeping Red Fescue, Russian Wild Rye or Crested Wheatgrass.

The zone*species interaction is one where the amount of biomass produced in zone 3 soil (17 dS/m) was not significantly less than that produced in zone 2 for either Alkali Grass or Tall Fescue. It was interesting to note that there were no significant differences between zone 1, zone 2 and zone 3 for any of the other species, meaning that the increase in salinity from 6 dS/m to 17 dS/m did not significantly reduce the amount of above ground biomass produced. Tall Fescue produced significantly more above ground biomass than all other species except Alkali Grass at the 17 dS/m level (zone 3), which produced significantly more biomass than Creeping Red Fescue, Russian Wild Rye and Crested Wheatgrass. There was no significant difference between Alkali Grass and Reed Canary Grass at this level. As in chapter 2, Tall Fescue and Alkali Grass produced more above ground biomass than the other species at the higher levels of salt, even up to 17 dS/m.

The 3-way interaction between flood*species*zone was significant and results are shown in Table A-7 in the appendix, not in a graph as this is a complicated relationship to illustrate and interpret.

Table 4.8: Analysis of Variance for above ground biomass for 6 species in zones 1, 2 and 3.

Sources of Variation	D.F.	F Value	Pr>F
Species	5	75.56	<0.0001
Zone	2	1.84	0.1819
Flood	3	1.41	0.2677
Species*Zone	10	4.64	<0.0001
Species*Flood	15	1.49	0.1038
Species*Zone*Flood	30	2.44	<0.0001

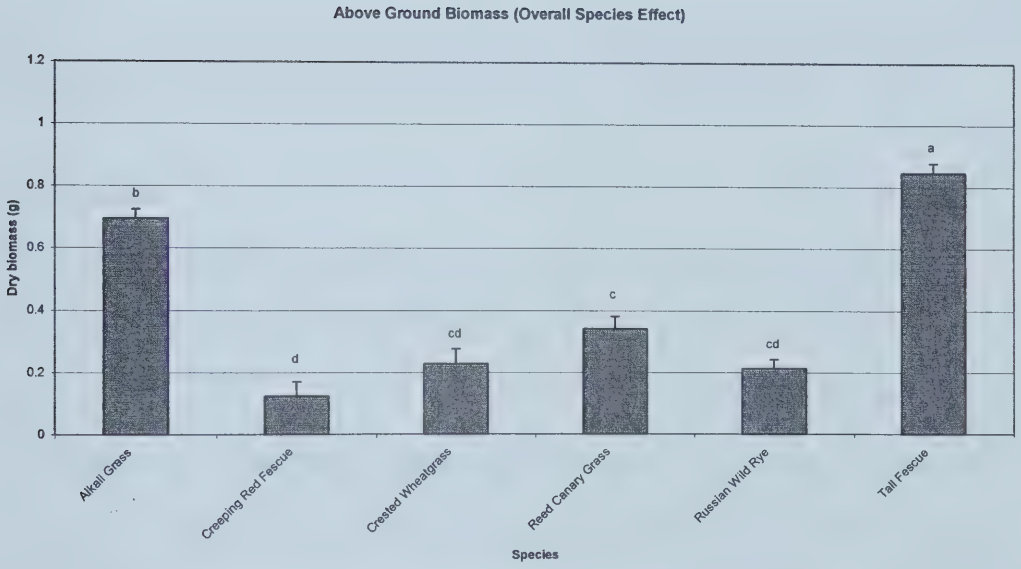

Figure 4.5: Average (LS means) above ground biomass produced per plant by each of the 6 species with adequate survival in zone 3 soil. Bars include Zone 1, 2 and 3 at all flooding levels. Bars with common letters are not significantly different (α =0.05).

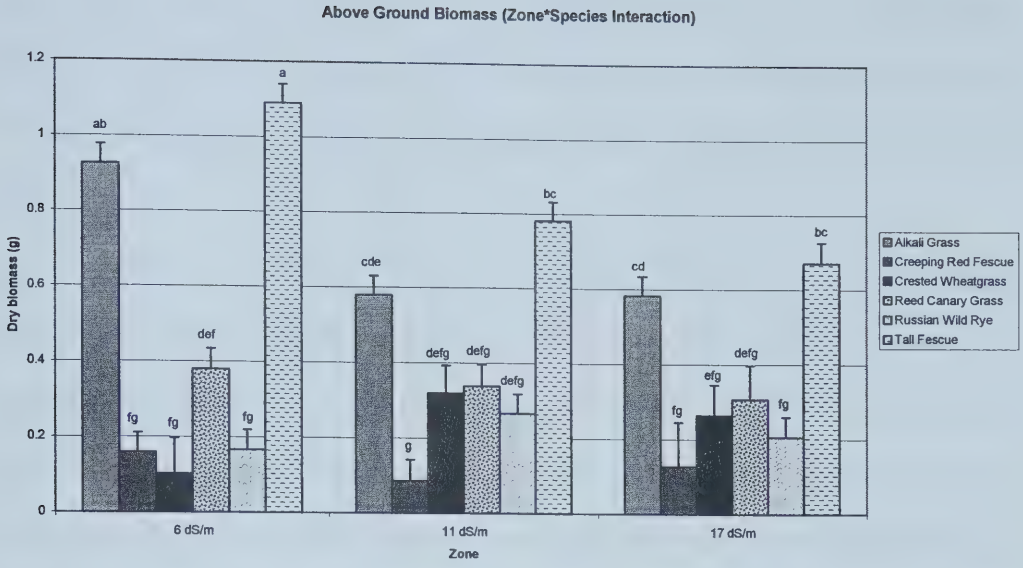

Figure 4.6: Average (LS means) above ground biomass produced per plant in soil zones 1, 2 and 3 by each of the 6 species with adequate survival in zone 3 soil. Bars include all flooding treatments. Bars with common letters are not significantly different (α =0.05).

4.4 Discussion

The trends in this experiment generally followed those in chapter 2, where increased salinity decreased survival and/or germination of different plant species to greater or lesser degrees, and where the more salt-tolerant plant species had better survival rates and greater levels of biomass than did less tolerant plants. The general results of this experiment could have been largely predicted from the results in chapter 2, where Alkali Grass, Tall Fescue and Russian Wild Rye had the greatest levels of survival at the greatest levels of salt, and where both Alkali Grass and Tall Fescue produced more above ground biomass than all other species at the greater levels of salt. The species with the lowest levels of survival were also largely predictable based on chapter 2 results, with the exception of the poor performance of Redtop. In chapter 2, according to the overall rankings of salt tolerance (Table 2.19), Redtop was rated as the 2nd most salt tolerant

species at the 12 dS/m level (combining the effect of salinity on survival, above ground biomass and below ground biomass). In this experiment Redtop produced less biomass and had a lower survival rate than 6 of the species tested, even in soil from zone 2 (11 dS/m).

One of the major problems with this experiment was that because of the toxic nature of the soils from zones 3 and 4, many of the plants died or failed to establish, especially in zone 4 soil. Because of the large standard errors caused by the missing data, the multiple comparisons of the LS means for above ground biomass production rarely showed significant differences between species and treatments except in extreme and rather obvious occasions (e.g., Alkali Grass and Tall Fescue producing double or triple the amount of biomass than the other species). In general, the results of species performance in sand were good predictors of species performance (especially survival) in soil collected from a very saline wetland-cropland ecotone, especially when considering the extreme ends of performance (the most and least salt tolerant species).

When the range of EC tested was expanded up to 29 dS/m, 47.2% of Alkali Grass seedlings, 22.2 % of Russian Wild Rye seedlings and 19.4% of Tall Fescue seedlings survived. It has been suggested that using biological methods to control salinity is preferable to the more expensive and invasive mechanical/structural controls such as subsurface drainage, as long as the salinity problem is not so severe as to completely inhibit plant growth (Eilers et al., 1995; Wentz, 2003b). These salt-tolerant species (Alkali Grass, Russian Wild Rye and Tall Fescue) may be suitable species to plant when the salt levels are so high as to severely inhibit plant growth of most other species. While these species were grown in a greenhouse under reasonably controlled conditions and

were not subjected to drought, the fact that any of the plants survived offers hope for plant establishment on very inhospitable sites.

Based on the results from this experiment and the correlation between this experiment and chapter 2, there is evidence to suggest that the concept of land-based management as described in chapter 1 (growing salt and flooding tolerant vegetation in saline and flooding prone areas) may be more successful than growing non-selected species, and thus warrants a larger scale field trial. Because of the differences in the ability of plants to survive and produce biomass at different levels of salinity and flooding, there would likely be some additional benefit to planting species specially selected for different locations surrounding the wetland as described in chapter 2 (inner and outer rings, with species selected primarily for their demonstrated tolerance of salinity levels within these rings).

Rickerl et al. (2000) showed that economic gains from using protective buffer strips/blocks around wetlands are close to, but less than, the net returns realized by maximizing annual crop production (no buffer). It was suggested that by providing federal monetary incentives through conservation programs, adoption of the beneficial practice of implementing buffer strips would be increased; however, the wetland-cropland ecotones in the study were not affected by salinization, and the species used for the buffer strips/blocks were not specifically selected for use in the areas (Rickerl et al., 2000). It is therefore possible that if the ecotone surrounding the wetland was affected by salinity, and the plants used in the buffer were selected based on demonstrated tolerance, there would be enough economic gain to make adoption of the practice feasible, even without government incentives.

4.5 Conclusions

This experiment was able to meet the main objectives of determining if plant performance in the sand was similar to plant performance in the ecotone soil and expanding the upper limit of salinity tested to determine if any of the selected species would be able to tolerate extreme levels of up to 29 dS/m.

The hypothesis that there would be similar plant growth trends in the ecotone soil when compared to the sand was not rejected, as there was a general correlation between plant performance in artificially salinized sand (chapter 2) and plant performance in soil collected from a saline wetland-cropland ecotone, where increased levels of salt decreased survival rates and the overall amount of biomass produced. The species with the greatest survival rates (Alkali Grass, Russian Wild Rye and Tall Fescue), greatest amount of above ground biomass (Alkali Grass and Tall Fescue), and the species with the lowest survival rates (Timothy, Redtop and Tufted Hair Grass) were largely predictable based on the results from chapter 2, with the exception of the low survival rates of Redtop. Due to the large amount of missing data and large standard errors, it was not possible to detect significant differences between the majority of species, even over increasing levels of salinity. The hypothesis that flooding would again have a stimulatory effect on biomass production was rejected, as flooding did not have a significant impact on growth.

Even at very high levels of salinity (up to 29 dS/m), some of the plants (Alkali Grass, Russian Wild Rye and Tall Fescue) were able to survive and produce biomass. Survival of these plants at such high levels offers a possibility of developing buffer systems that adhere to the principles of land-based management, thus allowing for biological control of salinization even in very severely affected areas.

Based on the correlation of results between chapter 2 and this trial, an intermediate step before field implementation, the next course of action should be to use the results of these experiments to design and implement a series of land-based buffer strips around several natural wetland-cropland ecotones. The purpose of the field trial would be to determine if the nutrient and sediment trapping ability, economic costs/gains and ability to stabilize the degree of salinization of the land-based buffer systems was greater than that of not using buffers, and using non-selected species for buffers.

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5. General Conclusion

5.1 Summary

Over the last decade, there has been increasing emphasis on practicing environmentally sustainable agriculture (Mc Rae et al. 2000). As part of this shifting emphasis, wetlands, previously viewed as wastelands to be drained and filled, are now beginning to be regarded as an important part of the landscape worthy of protection (Environment Canada, 1998). As a result, management practices that protect wetlands by reducing siltation, eutrophication and chemical pollution have been studied. One of the more promising solutions has been the use of vegetated buffer strips (Osborne and Kovacic, 1993; Barfield and Albrecht, 1982; Rickerl et al., 2000).

Vegetated buffer strips planted around wetlands or along riparian areas offer protection by slowing runoff which then allows for filtration, deposition, absorption, adsorption, decomposition and volatilization of agricultural fertilizers, pesticides and sediments (Dillaha et al., 1989). Although shown to be effective in many situations, the cost associated with reducing the amount of land available for annual crop production is one factor that may hinder inclusion of vegetated buffer strips into normal land-use practice (Rickerl et al., 2000). The costs associated with using vegetated buffer strips may be less of a problem in areas affected by salinity because of the negative effects that soil salinity has on crop yield. Many of the wetlands in the prairie region of North America are affected by some degree of soil salinization due to the presence of sulfate salts in the parent material (glacial till) (Greenlee et al., 1968; Keller and van der Kamp, 1988).

By managing wetland-cropland ecotones using the theory of land-based management, plant species composition/position within the buffer strips should be planned by mimicking the distributions found in natural systems. More salt tolerant species should be planted in more saline areas, and flood tolerant species should be planted in areas most likely to be flooded in order to maximize plant growth throughout the ecotone.

The purpose of this project was to find several plant species that would be good candidates for use in vegetated buffer strips, used to protect wetlands in agricultural areas affected by salinity. While many researchers have shown the positive benefits of using vegetated buffer strips to protect riparian areas, the main premise behind this research was that by using the theory of land-based management, a better multi-purpose buffer strip could be designed. Plants used in the "improved" buffer strips would be chosen based on their demonstrated tolerance to existing salt and moisture gradients within the ecotone, and thus have increased survival as well as greater above and below ground biomass. Greater biomass would likely provide better wildlife habitat, better sediment and chemical trapping ability offering greater wetland protection, as well as higher forage production yields that may offset the economic loss from reduced annual cropping, greater carbon sequestration, reduced risk of soil erosion, and eventually, may help to reduce the extent and severity of salinization of the area. The specially designed wetland-cropland buffer strips will likely offer better wetland protection than growing annual crops in the area or using non-selected plant species in the buffer strips, while still allowing for agricultural land use across the broader landscape.

5.2 Synthesis

Throughout this project, it was determined that salinity was the most important factor determining plant success; flooding with durations of up to 4 weeks often had a negligible or even stimulatory effect. It was expected that finer textured soils (clay and loam) would be more negatively affected than coarser textured growth medium (sand) by the longer durations of flooding. However, in chapter 3, it was shown that plant growth in all three different textured soils (sand, loam and clay) were actually stimulated by flooding, and that plant growth in clay textured soil was stimulated more than plant growth in loam textured soil, which was stimulated more than in the sand, regardless of flooding durations or salinity treatments. Due to a similar ranking in initial nutrient status (clay > loam > sand), it was impossible to suggest whether the trend of increased plant growth with smaller particle size was because of soil texture or because of the initial soil fertility. The root to shoot ratios showed the opposite trend, where plants grown in sand had higher ratios than plants in clay or loam soils. This may have been due to a combination of preference for the plants in the clay and loam soils to allocate carbon to produce above ground biomass rather than below ground biomass due to the decreased aeration of growth media (smaller particle and pore size) when compared to the sand, as well as increased root recovery from plants grown in sand when compared to those grown in the soil.

While many of the species tested performed well at the lower levels of salt (0 to 6 dS/m), Alkali Grass and Tall Fescue were the most salt tolerant species, with both high rates of survival and biomass at high levels of salt (12 to 17 dS/m). Even at 29 dS/m, Alkali Grass had a survival rate of just less than 50%; both Russian Wild Rye and Tall

Fescue also had reasonable rates of survival at approximately 20%. While these conditions are extreme, the fact that some of the plants survived offers hope for biological mitigation of very saline areas. Because all of the species tested have different strengths and weaknesses, it is important not only to select species based on salt and flooding tolerance but also based on the desired land use. For example, if hay production is a primary concern, then Creeping Red Fescue and Tufted Hair Grass are not good candidates, but if erosion control is important, then both species are suitable (Table 2.23).

Analysis of the soil collected from the wetland-cropland ecotone near Mundare, Alberta showed that there was a very evident salinity gradient (from 6 to 29 dS/m). Several distinct zones, each with different dominant vegetation, were observed and as was expected, the changes in vegetation also coincided with pronounced changes in EC. The results presented in chapters 2 and 4 indicate that not all plant species perform to the same degree throughout all salt and flooding treatments. There is therefore a good rationale for initiating a research program to test the performance of vegetated buffer strips designed using the theory of land-based management in the field.

5.3 Further Research

In chapter 2 it was suggested that because the effect of flooded conditions was not as deleterious as predicted, it is more important to select species for locations within the ecotone buffer strip primarily based on salt tolerance in all but the most flood prone areas (e.g., the ring of land surrounding open water) (Figure 2.39). The figure in chapter 2 (Figure 2.40) illustrates the most suitable species of those tested for use within different locations of the wetland-cropland ecotone depending on the extent of the salinity problem.

In the wetter areas, and areas expected to be subjected to periodic flooding within the ecotone, the following species would be suitable, depending on the desired land use: Reed Canary Grass, Crested Wheatgrass, Redtop, Timothy and Tall Fescue. If the ecotone is subject to high salinity, only plants with demonstrated salt tolerance should be used, regardless of the flooding potential, as salt was the biggest factor determining plant success. The most saline areas within the ecotone should be planted with one or more of the following: Alkali Grass, Tall Fescue, Redtop, Reed Canary Grass and Creeping Red Fescue, depending on the desired land use. Areas within the ecotone with low to moderate salinity and not at risk for flooding can be planted with one or more of the following: Redtop, Crested Wheatgrass, Tall Fescue and Timothy. Caution should be used when using Redtop, as although it did very well in the experiment in chapter 2, it did not do well in the experiment in chapter 4.

Table 2.23: Most beneficial species for hay production, erosion control, wildlife / pasture use and salt tolerance.

Hay Production (Alberta Agriculture, 1981)	Erosion Control (Alberta Agriculture, 1981)	Wildlife / Pasture (Alberta Agriculture, 1981)	Most Salt Tolerant (from chapter 2 results)
Timothy	Tall Fescue	Russian Wild Rye	Alkali Grass
Tall Fescue	Redtop	Creeping Red Fescue	Redtop
Crested Wheatgrass	Reed Canary Grass	Crested Wheatgrass	Tall Fescue
Russian Wild Rye	Creeping Red Fescue	Tufted Hair Grass	Creeping Red Fescue
Reed Canary Grass	Tufted Hair Grass	Tall Fescue	
	Crested Wheatgrass		

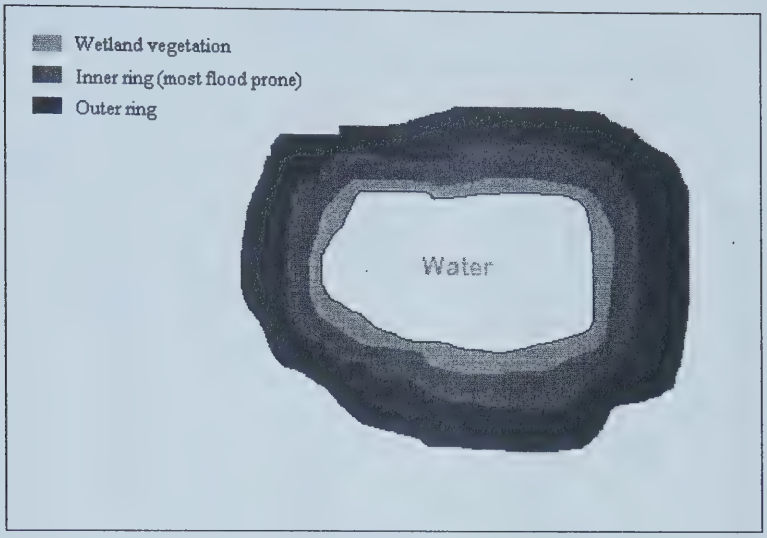

Figure 2.39: The wetland-cropland ecotone depicted as two main zones, the inner and outer rings surrounding the wetland.

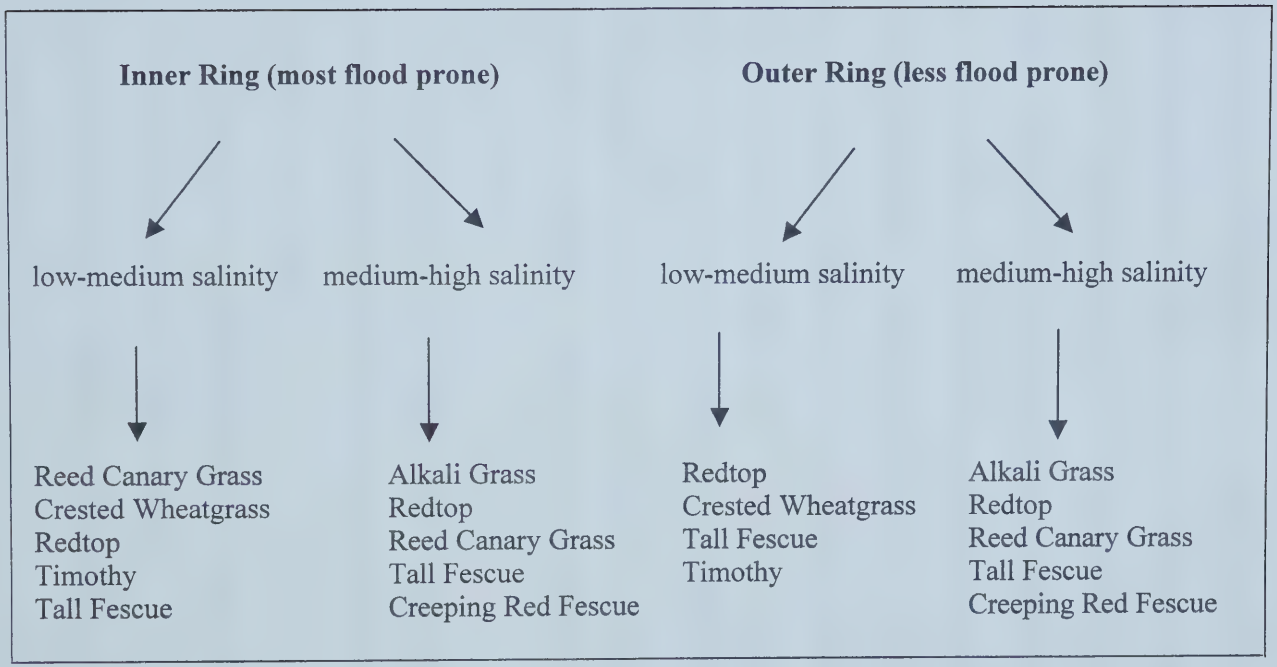

Figure 2.40: Most suitable species for planting within different locations within wetland-cropland ecotones.

The next logical step in this research program would be to design a field trial using the results and suggestions reported throughout this thesis to determine if the espoused benefits of vegetated buffer strips are applicable and realized in real salt affected wetland-cropland ecotones throughout the prairie pothole region. Effectiveness in removing nutrients (nitrogen and phosphorus) and sediments is generally increased with increased buffer widths (Dillaha et al., 1989; Magette et al., 1989; Bernard et al., 2000). Because of this, and in order to minimize excess labor associated with managing all wetland-cropland ecotones, it would be most practical to focus on the larger, permanent and semi-permanent wetland areas with ecotones of sufficient size so as to be able to maneuver agricultural machinery. The "improved" buffer strips are more likely to be cost effective in ecotones affected by salinity due to decreased crop yields associated with these areas. A properly designed field trial could test many of the following on numerous wetland-cropland ecotones with varying degrees of salinity:

1. Economic costs/benefits of implementing vegetated buffer strips over annual cropping systems.
2. Carbon sequestration of the buffer strips versus annual cropping systems.
3. Sediment, nutrient and pesticide trapping ability of the buffer strips versus annual cropping systems.
4. The long-term effect of buffer strips versus the effect of annual cropping systems on the salinization of affected areas.
5. The increase/decrease in biodiversity with vegetated buffer strips over annual cropping systems.

5.4 References

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6. Appendix

Table A-1: LS means and standard errors for the 3 way interaction (species*salt*flood) for below ground biomass in Trial 1.

Species	Flood (weeks)	0 dS/m		4 dS/m		8 dS/m		12 dS/m	
		LS mean	S.E.	LS. mean	S.E.	L.S. mean	S.E.	L.S. mean	S.E.
Alkali Grass	0	0.603	0.055	0.640	0.055	0.565	0.055	0.300	0.055
	1	0.433	0.055	0.583	0.055	0.589	0.055	0.403	0.055
	2	0.313	0.055	0.424	0.055	0.497	0.055	0.551	0.055
	4	0.259	0.055	0.243	0.055	0.291	0.055	0.252	0.055
Crested Wheatgrass	0	1.280	0.058	1.113	0.055	0.374	0.069	0.300	0.098
	1	1.188	0.055	1.132	0.055	0.501	0.068	0.193	0.098
	2	1.193	0.055	0.572	0.061	0.384	0.074	0.241	0.074
	4	0.835	0.055	0.885	0.058	0.560	0.061	0.119	0.099
Redtop	0	1.286	0.058	0.836	0.055	1.023	0.090	0.293	0.086
	1	0.508	0.055	0.871	0.064	0.403	0.068	0.309	0.058
	2	0.990	0.055	0.649	0.058	0.568	0.064	0.262	0.064
	4	0.760	0.055	0.531	0.058	0.660	0.064	0.271	0.061
Reed Canary Grass	0	0.586	0.055	0.671	0.061	0.470	0.061	0.380	0.087
	1	0.468	0.061	0.545	0.058	0.452	0.055	0.240	0.076
	2	0.536	0.061	0.460	0.064	0.407	0.061	0.249	0.076
	4	0.746	0.055	0.549	0.055	0.649	0.061	0.526	0.099
Russian Wild Rye	0	0.380	0.061	0.493	0.069	0.519	0.064	0.226	0.058
	1	0.319	0.069	1.215	0.079	0.359	0.061	0.164	0.069
	2	0.229	0.080	0.345	0.055	0.249	0.061	0.201	0.064
	4	0.299	0.068	0.318	0.086	0.268	0.073	0.135	0.068
Tufted Hair Grass	0	0.640	0.061	0.507	0.061	0.343	0.061	0.136	0.074
	1	0.854	0.075	0.492	0.074	0.271	0.080	0.058	0.087
	2	0.576	0.058	0.420	0.058	0.301	0.074	0.199	0.079
	4	0.656	0.058	0.451	0.064	0.236	0.079	0.052	0.090

Table A-2: LS means and standard errors for the 3 way interaction (species*salt*flood) for below ground biomass in Trial 2.

Species	Flood (weeks)	0 dS/m		4 dS/m		8 dS/m		12 dS/m	
		LS mean	S.E.	LS mean	S.E.	LS mean	S.E.	LS mean	S.E.
Creeping Red Fescue	0	0.203	0.022	0.219	0.022	0.133	0.025	0.059	0.023
	1	0.315	0.022	0.127	0.021	0.141	0.022	0.052	0.022
	2	0.365	0.022	0.165	0.022	0.084	0.022	0.078	0.023
	4	0.263	0.021	0.135	0.027	0.109	0.024	0.052	0.021
Tall Fescue	0	0.389	0.021	0.383	0.021	0.372	0.021	0.227	0.021
	1	0.796	0.021	0.316	0.021	0.393	0.021	0.235	0.021
	2	0.732	0.021	0.332	0.022	0.397	0.021	0.286	0.021
	4	0.622	0.028	0.432	0.021	0.390	0.021	0.247	0.021
Timothy	0	0.199	0.026	0.159	0.022	0.093	0.026	0.034	0.042
	1	0.595	0.022	0.200	0.023	0.152	0.023	0.02	0.038
	2	0.339	0.023	0.153	0.024	0.093	0.026	0.035	0.033
	4	0.417	0.022	0.192	0.029	0.082	0.026	0.116	0.055

Table A-3: Ranges of essential mineral contents of temperate pasture grasses (dry basis) (Adapted from McDonald et al., 1988).

Element	Low (%)	Normal (%)	High (%)
Potassium	<1.20	1.50-3.00	>3.50
Calcium	<0.20	0.25-0.35	>0.60
Phosphorus	<0.20	0.20-0.35	>0.40
Magnesium	<0.10	0.12-0.20	>0.25

Table A-4: LS means and standard errors for the 4 way interaction (species*salt*flood*texture) for below ground biomass.

Treatment		Texture	Alkali Grass		Tall Fescue	
Salt (dS/m)	Flood (Weeks)		LS mean	Standard Error	LS mean	Standard Error
0	0	Clay	0.1152	0.0122	0.2600	0.0122
0	1	Clay	0.1536	0.0122	0.2654	0.0122
0	2	Clay	0.1418	0.0122	0.4765	0.0122
0	4	Clay	0.1631	0.0122	0.4514	0.0122
4	0	Clay	0.1521	0.0122	0.3399	0.0122
4	1	Clay	0.1542	0.0122	0.3519	0.0122
4	2	Clay	0.3363	0.0154	0.3604	0.0122
4	4	Clay	0.1354	0.0122	0.3812	0.0122
8	0	Clay	0.1438	0.0122	0.2036	0.0122
8	1	Clay	0.0813	0.0122	0.2312	0.0122
8	2	Clay	0.1155	0.0122	0.2279	0.0122
8	4	Clay	0.0679	0.0122	0.2028	0.0122
12	0	Clay	0.1507	0.0122	0.2563	0.0122
12	1	Clay	0.1288	0.0122	0.2194	0.0122
12	2	Clay	0.1221	0.0122	0.2769	0.0122
12	4	Clay	0.0919	0.0122	0.2151	0.0122
0	0	Loam	0.1146	0.0122	0.2422	0.0122
0	1	Loam	0.0979	0.0122	0.2470	0.0122
0	2	Loam	0.0929	0.0122	0.3464	0.0122
0	4	Loam	0.1055	0.0122	0.2507	0.0122
4	0	Loam	0.1187	0.0122	0.2296	0.0122
4	1	Loam	0.1359	0.0122	0.2583	0.0122
4	2	Loam	0.1217	0.0122	0.3234	0.0122
4	4	Loam	0.1808	0.0122	0.3298	0.0122
8	0	Loam	0.0895	0.0122	0.2064	0.0122
8	1	Loam	0.0694	0.0122	0.1681	0.0122
8	2	Loam	0.0691	0.0122	0.1720	0.0122
8	4	Loam	0.0565	0.0122	0.1563	0.0122
12	0	Loam	0.0785	0.0122	0.1642	0.0122
12	1	Loam	0.0890	0.0122	0.1743	0.0122
12	2	Loam	0.1175	0.0122	0.1436	0.0122
12	4	Loam	0.0906	0.0122	0.1553	0.0122
0	0	Sand	0.1146	0.0122	0.2898	0.0122
0	1	Sand	0.1714	0.0122	0.3510	0.0122
0	2	Sand	0.2172	0.0122	0.3990	0.0122
0	4	Sand	0.0735	0.0122	0.3191	0.0122
4	0	Sand	0.1256	0.0122	0.2412	0.0122
4	1	Sand	0.1928	0.0122	0.3143	0.0122
4	2	Sand	0.1459	0.0122	0.3482	0.0122
4	4	Sand	0.1248	0.0122	0.2384	0.0122
8	0	Sand	0.1055	0.0122	0.1388	0.0122
8	1	Sand	0.0956	0.0122	0.1557	0.0122
8	2	Sand	0.0824	0.0122	0.1268	0.0122
8	4	Sand	0.0500	0.0122	0.1327	0.0122
12	0	Sand	0.1409	0.0122	0.1486	0.0122
12	1	Sand	0.1338	0.0122	0.1593	0.0122
12	2	Sand	0.0822	0.0122	0.1538	0.0122
12	4	Sand	0.0762	0.0122	0.2100	0.0127

Table A-5: LS means and standard errors for the 4 way interaction (species*salt*flood*texture) for root to shoot ratio.

Treatment			Alkali Grass		Tall Fescue	
Salt (dS/m)	Flood (Weeks)	Texture	LS mean	Standard Error	LS mean	Standard Error
0	0	Clay	0.1234	0.0240	0.2221	0.0240
0	1	Clay	0.1547	0.0240	0.2208	0.0240
0	2	Clay	0.1151	0.0240	0.2712	0.0240
0	4	Clay	0.0990	0.0240	0.2184	0.0240
4	0	Clay	0.1287	0.0240	0.3090	0.0240
4	1	Clay	0.1366	0.0240	0.2489	0.0240
4	2	Clay	0.2526	0.0304	0.2215	0.0240
4	4	Clay	0.1043	0.0240	0.1877	0.0240
8	0	Clay	0.1489	0.0240	0.2182	0.0240
8	1	Clay	0.0863	0.0240	0.2389	0.0240
8	2	Clay	0.0998	0.0240	0.1997	0.0240
8	4	Clay	0.0558	0.0240	0.1635	0.0240
12	0	Clay	0.1208	0.0240	0.2381	0.0240
12	1	Clay	0.1152	0.0240	0.2250	0.0240
12	2	Clay	0.0970	0.0240	0.2587	0.0240
12	4	Clay	0.0732	0.0240	0.1946	0.0240
0	0	Loam	0.1774	0.0240	0.3547	0.0240
0	1	Loam	0.1115	0.0240	0.2757	0.0240
0	2	Loam	0.1066	0.0240	0.2740	0.0240
0	4	Loam	0.1040	0.0240	0.1892	0.0240
4	0	Loam	0.1804	0.0240	0.3098	0.0240
4	1	Loam	0.1416	0.0240	0.2966	0.0240
4	2	Loam	0.1702	0.0240	0.2996	0.0240
4	4	Loam	0.1502	0.0240	0.2409	0.0240
8	0	Loam	0.1268	0.0240	0.2807	0.0240
8	1	Loam	0.1075	0.0240	0.2527	0.0240
8	2	Loam	0.1002	0.0240	0.2302	0.0240
8	4	Loam	0.0730	0.0240	0.1557	0.0240
12	0	Loam	0.1121	0.0240	0.2607	0.0240
12	1	Loam	0.1088	0.0240	0.2525	0.0240
12	2	Loam	0.1079	0.0240	0.2233	0.0240
12	4	Loam	0.0858	0.0240	0.1721	0.0240
0	0	Sand	0.3237	0.0240	0.5315	0.0240
0	1	Sand	0.3634	0.0240	0.5752	0.0240
0	2	Sand	0.3207	0.0240	0.4404	0.0240
0	4	Sand	0.1367	0.0240	0.3312	0.0240
4	0	Sand	0.2851	0.0240	0.4459	0.0240
4	1	Sand	0.3687	0.0240	0.4735	0.0240
4	2	Sand	0.2553	0.0240	0.4811	0.0240
4	4	Sand	0.1930	0.0240	0.2379	0.0240
8	0	Sand	0.3039	0.0240	0.3163	0.0240
8	1	Sand	0.3116	0.0240	0.3309	0.0240
8	2	Sand	0.1896	0.0240	0.2388	0.0240
8	4	Sand	0.0901	0.0240	0.2055	0.0240
12	0	Sand	0.3529	0.0240	0.3406	0.0240
12	1	Sand	0.3040	0.0240	0.3025	0.0240
12	2	Sand	0.1739	0.0240	0.2958	0.0240
12	4	Sand	0.1219	0.0240	0.3167	0.0251

Table A-6: LS means and standard errors for the 3 way interaction (flood*species*zone) for above ground biomass produced in zone 1 and 2 (includes all species).

Flood Treatment (Weeks)	Species	Zone 1 (6 dS/m)		Zone 2 (11 dS/m)	
		LS mean	S.E.	LS mean	S.E.
0	Alfalfa	0.261	0.096	0.082	0.090
0	Alkali Grass	0.613	0.090	0.492	0.090
0	Bird's-foot Trefoil	0.362	0.113	0.098	0.096
0	Creeping Red Fescue	0.106	0.090	0.103	0.090
0	Crested Wheatgrass	0.151	0.103	0.321	0.096
0	Reed Canary Grass	0.512	0.103	0.442	0.090
0	Redtop	0.239	0.096	0.159	0.096
0	Russian Wild Rye	0.145	0.090	0.315	0.090
0	Timothy	0.153	0.111	0.075	0.158
0	Tall Fescue	0.833	0.090	0.789	0.090
0	Tufted Hair Grass	0.066	0.096	0.143	0.156
1	Alfalfa	0.194	0.090	0.068	0.114
1	Alkali Grass	0.830	0.090	0.440	0.090
1	Bird's-foot Trefoil	0.186	0.090	0.102	0.096
1	Creeping Red Fescue	0.189	0.096	0.076	0.103
1	Crested Wheatgrass	0.115	0.111	0.188	0.124
1	Reed Canary Grass	0.277	0.090	0.106	0.111
1	Redtop	0.061	0.113	0.129	0.163
1	Russian Wild Rye	0.130	0.090	0.188	0.090
1	Timothy	0.141	0.197	0.028	0.124
1	Tall Fescue	1.035	0.090	0.731	0.090
1	Tufted Hair Grass	0.231	0.123	0.227	0.122
2	Alfalfa	0.133	0.096	0.036	0.096
2	Alkali Grass	1.505	0.090	0.458	0.090
2	Bird's-foot Trefoil	0.147	0.096	0.086	0.090
2	Creeping Red Fescue	0.236	0.090	0.086	0.090
2	Crested Wheatgrass	0.045	0.111	0.207	0.123
2	Reed Canary Grass	0.289	0.096	0.257	0.096
2	Redtop	0.148	0.111	0.210	0.090
2	Russian Wild Rye	0.156	0.096	0.271	0.090
2	Timothy	0.067	0.156	0.130	0.103
2	Tall Fescue	1.057	0.090	0.917	0.090
2	Tufted Hair Grass	0.112	0.111	0.051	0.136
4	Alfalfa	0.102	0.090	0.183	0.139
4	Alkali Grass	0.757	0.090	0.927	0.090
4	Bird's-foot Trefoil	0.250	0.096	0.060	0.096
4	Creeping Red Fescue	0.103	0.090	0.092	0.111
4	Crested Wheatgrass	0.130	0.274	0.535	0.163
4	Reed Canary Grass	0.437	0.090	0.546	0.103
4	Redtop	0.207	0.096	0.249	0.103
4	Russian Wild Rye	0.234	0.096	0.291	0.090
4	Timothy	0.325	0.111	0.181	0.096
4	Tall Fescue	1.436	0.090	0.689	0.090
4	Tufted Hair Grass	0.177	0.137	0.413	0.136

Table A-7: LS means and standard errors for the 3 way interaction (flood*species*zone) for above ground biomass produced in zone 1, 2 and 3 (does not include all species).

Flood Treatment (Weeks)	Species	Zone 1 (6 dS/m)		Zone 2 (11 dS/m)		Zone 3 (17 dS/m)	
		LS mean	S.E.	LS mean	S.E.	LS mean	S.E.
0	Alkali Grass	0.613	0.102	0.492	0.102	0.709	0.102
0	Creeping Red Fescue	0.106	0.102	0.103	0.102	0.156	0.222
0	Crested Wheatgrass	0.157	0.117	0.320	0.109	0.316	0.134
0	Reed Canary Grass	0.518	0.117	0.442	0.102	0.330	0.222
0	Russian Wild Rye	0.145	0.102	0.315	0.102	0.165	0.109
0	Tall Fescue	0.833	0.102	0.789	0.102	1.051	0.119
1	Alkali Grass	0.830	0.102	0.440	0.102	0.415	0.102
1	Creeping Red Fescue	0.191	0.109	0.072	0.117	0.033	0.319
1	Crested Wheatgrass	0.120	0.126	0.176	0.141	0.170	0.144
1	Reed Canary Grass	0.277	0.102	0.106	0.125	0.396	0.231
1	Russian Wild Rye	0.130	0.102	0.188	0.102	0.261	0.109
1	Tall Fescue	1.035	0.102	0.731	0.102	0.254	0.109
2	Alkali Grass	1.505	0.102	0.458	0.102	0.710	0.102
2	Creeping Red Fescue	0.236	0.102	0.086	0.102	0.143	0.130
2	Crested Wheatgrass	0.045	0.125	0.167	0.141	0.165	0.117
2	Reed Canary Grass	0.286	0.109	0.249	0.109	0.305	0.125
2	Russian Wild Rye	0.152	0.109	0.271	0.102	0.229	0.109
2	Tall Fescue	1.057	0.102	0.917	0.102	0.748	0.109
4	Alkali Grass	0.757	0.102	0.927	0.102	0.499	0.102
4	Creeping Red Fescue	0.103	0.102	0.084	0.127	0.179	0.229
4	Crested Wheatgrass	0.086	0.313	0.613	0.190	0.406	0.229
4	Reed Canary Grass	0.437	0.102	0.557	0.116	0.198	0.116
4	Russian Wild Rye	0.240	0.109	0.291	0.102	0.170	0.109
4	Tall Fescue	1.436	0.102	0.689	0.102	0.632	0.102

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